QUANTITATIVE EVALUATION OF MULTIBAND PHOTOGRAPHIC TECHNIQUES

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Final Report   *31 December 1970*

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ABSTRACT

The primary objective of the research presented in this report was to determine, with the aid of photo interpreters, the usefulness of multiband photography. Environmental parameters, within five test sites located in California and Arizona, having known importance to agriculturalists and foresters were selected for study, i.e., agricultural crop types, forest vegetation types and tree species composition. Quantitative analyses were made, using a large group of skilled photo interpreters, of the interpretability of (1) multiband black-and-white photos viewed separately, (2) multiband black-and-white photos combined into true and false color composites, and (3) color and color infrared photos obtained simultaneously with the multiband black-and-white photography. In each of these case studies, test results indicated that multiband photography consistently yielded higher interpretation accuracies than any type of single band photography. In addition, black-and-white multiband photos properly procured and displayed as false-color composite imagery in all cases rendered as much (or as little) information as conventional tri-emulsion layer color or false-color infrared films. Furthermore, by drawing on the flexibility afforded by multiband photography (i.e., optimum false-color enhancements of properly selected band-passes), in certain instances the composite imagery was superior to all other types of photography being tested.

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ACKNOWLEDGMENTS

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INTRODUCTION

This report documents research performed by personnel of the Forestry Remote Sensing Laboratory, University of California at Berkeley, on contract NAS 9-9577 entitled "Quantitative Evaluation of Multiband Photographic Techniques." The primary objective of this work was to make a quantitative evaluation of current techniques used in the acquisition and interpretation of multiband photography. In specific cases, recommendations as to optimum combinations of multiband and multidate imagery for the study of various earth resources have resulted from this study.

The study consisted of five phases: (1) selecting study areas within existing NASA test sites that contained a variety of forest and agricultural resources; (2) procuring multiband imagery of the selected study areas; (3) developing an experimental procedure that allowed quantitative analyses to be made of the multiband data; (4) determining the information content on the multiband imagery through photo interpretation testing, negative density measurements and electronic image enhancements; and (5) analyzing and compiling results of the tests in a quantitative, rather than a qualitative fashion.

Our findings from this study are also included, in an abriged form, in a NASA publication entitled "Manual of Multiband Photography," which has been completed and submitted to the Manned Spacecraft Center, Houston, Texas.

PROCUREMENT OF MULTIBAND IMAGERY OF TEST SITES

SELECTION OF TEST SITES

Prior to the date of contract award and continuing through this contract reporting period, intensive ground truth operations have been carried out in many areas of the western United States by personnel at the Forestry Remote

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Sensing Laboratory (FRSL). For each location in which our group has had

experience, an examination was made of the availability of ground truth

data, the existence of useful multiband imagery and the level of cooperation

between our group and the agency responsible for inventorying or managing

the resources for that area. This process of scrutinizing several potential

study areas resulted in the selection of five principle sites for investiga-

tion under this contract: Yosemite (forest resources), Bucks Lake (forest

resources), Davis (agricultural resources), Imperial Valley (agricultural

resources) and Phoenix-Mesa (agricultural resources). See Figure 1.

EXISTING MULTIBAND IMAGERY OF TEST SITES

A great amount of multiband photography exists of the five test sites

selected. The following discussion provides information on both the type and

history of acquisition of this photography.

The potential usefulness of multiband photography was recognized long

before adequate aerial camera equipment became available for taking such

photography. During these early stages of technique development, the researcher

was forced to use multiple flight path photography in his investigations.

Merely by having an aircraft make successive passes over the same point on

the ground and by changing either the film type or filter on each pass,

suitable multiband photographs were obtained for experimental purposes.

Multiband photos procured in this manner were taken of several wildland areas

in the western United States. Among the first areas in which extensive research

was performed using this kind of photography was the Bucks Lake test site in

northern California. However, the usefulness of multiband photography ob-

tained in this manner was obviously limited due to problems of image calibra-

tion, lack of geometric compatibility, and temporal inconsistancies. Never-

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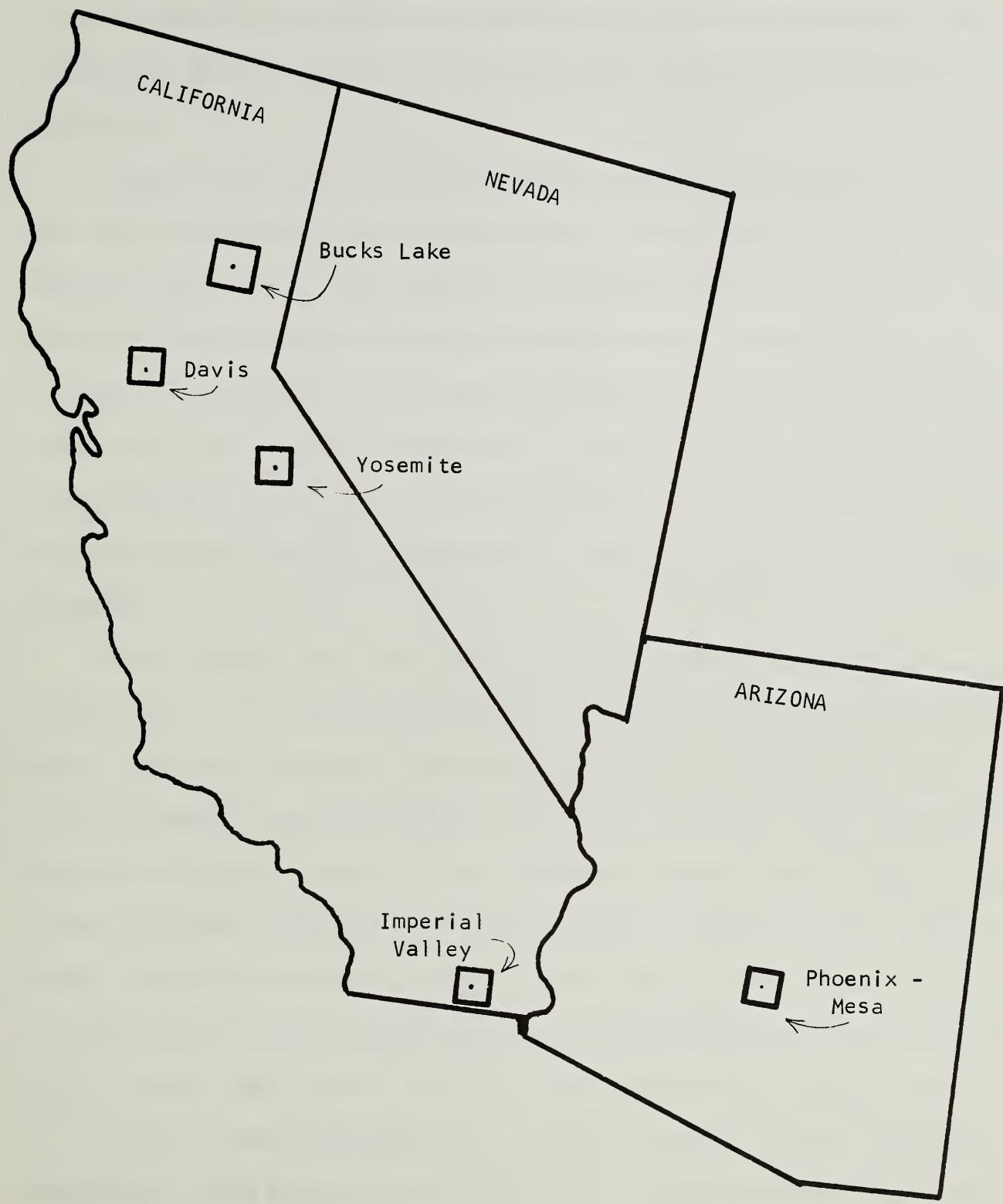
Figure 1. Five principal test sites were selected for study in which a wide variety of forest and agricultural resource features and conditions were present.

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theless, these early exercises in gathering multiband data as well as the images themselves provided an excellent opportunity to investigate multiband techniques, and the resulting data were used extensively for demonstrative purposes.

Many of the difficulties associated with using multiple flight path multiband photography (costs, registration, timing, etc.) were overcome merely by mounting a frame camera in a rigid position on a stationary platform and taking multiband photos of a target array arranged beneath the camera station. In this way, and in lieu of suitable airborne multiband equipment, photos using any number of film/filter combinations were made of exactly the same ground area with just a few seconds elapsing between exposures. Thus, multiband photos which are geometrically identical were quickly and economically obtained.

Our group has used this method of image acquisition with good results, particularly at the Yosemite and Davis test sites. The Glacier Point Overlook, 3,000 feet vertically above the valley floor, was the ideal camera station at Yosemite, while the catwalk on a 150-foot water tower provided an excellent platform at Davis. Tone signatures derived from multiband images taken from these camera stations for both natural objects (soils, crops and forest types) and artificial targets (color panels, grey scales and models) were analyzed and the results from these studies have been reported (Colwell et al., 1965, 1966; Colwell and Lent, 1967; and Carneggie et al., 1967).

Prior to the development of a reliable multilens camera, multiband photography could be experimented with but its usefulness could not easily be tested. A major step was taken towards testing theory when the early models of multilens cameras (e.g., the Itek Corporation's 9-lens camera, University of Michigan's 16-lens camera, and Cartwright Aerial Surveys' 4-lens spectro-

zonal camera) were fabricated. Further experimentation with these systems led to the design and implementation of a highly controlled multiband experiment in 1967.

During the summer season, 1967, multiband aerial photography was taken of the Bucks Lake and Davis test sites using an optically and geometrically calibrated 4-lens multispectral camera developed by personnel of the Science and Engineering Group at Long Island University (LIU). Concurrent with these overflights, field crews gathered detailed ground truth information on agricultural crops and field conditions at Davis, and on vegetation/soil types at Bucks Lake.

RESULTS FROM PREVIOUS EXPERIMENTS

Analysis of the 1967 multiband photography reaffirmed the conclusions derived from previous experiments that, depending upon the complexity of information desired, accurate interpretation of a single photo image can be a tedious and difficult task. Moreover, conscientious attempts at the interpretation of multiband imagery, taken by sensing in several different spectral bands and acquired on several different dates of large agricultural or forested area, soon saturates the human mind. As the complexity of tone signatures increases and the volume of data accumulates, conventional interpretation processes soon break down. These studies again emphasized the need for developing a means of facilitating the photo interpreters' task while working with multiband photography.

Among the advanced techniques being pursued for the purpose of alleviating these interpretation problems is additive color image enhancement. For the technique to be successful, however, it is essential that each frame of imagery taken of the same area have identical orientation and geometry. This

requirement was fulfilled in 1967 when imagery was obtained with the LIU bore-sighted multilens camera. Theoretically, by combining multiband data in superimposed form, any number of images (two, three or four sometimes being the optimum) can be viewed simultaneously, and minute tone differences between objects of interest can be enhanced and presented to the image analyst as unique color differences in the composite image. The latter aspect of this technique exploits the ability of the human eye to perceive a tremendous number of variations in color as compared to relatively few variations in black-and-white (B/W) tones.

The procedure used to make additive color image enhancements with the aid of an optical combiner at the FRSL can be summarized as follows: (1) B/W multiband photos of an area are obtained simultaneously in each of several spectral bands; (2) a lantern slide is made from each of these photos; (3) by means of a multiple projector system, the multiband photos are optically combined in common register onto a reflecting or rear-viewing screen; and (4) by inserting a colored absorption filter into the optical path of each projected image, a single false-color composite image is created.

The LIU multiband viewer, on which many of the false-color images seen in this report were made, embodies the additive color principles in a console which displays a rear-projection screen to the operator. This device is unique in that it utilizes the pre-registered sets of multiband photos taken on one roll of film in the LIU multiband camera. Registration is easily maintained as the operator proceeds from one multiband presentation to the next.

ACQUISITION OF NEW MULTIBAND IMAGERY

Results from all previous studies, including conclusions drawn from the 1967 experiment, indicate that current techniques used in the acquisition and interpretation of multiband photography must be quantitatively evaluated. In

prior studies, primarily qualitative comparisons had been made of the inter-
pretability of the various combinations of multiband and color reconstituted
photos.

The purpose of the 1969 multiband photo experiment reported on herein
was to quantitatively test the ability of a photo interpreter to extract
useful resource information from multiband imagery presented to him in a
number of different ways. In order to accomplish this task, it was necessary
to procure a large number of multiband photos of several areas within each
test site. Again, as was the case in 1967, the LIU equipment was used to
acquire the necessary multiband photography. The photo missions were planned
in such a way that a large number of resource features or conditions occurring
in each test site would be imaged on the photography, allowing a sufficient
sample size for interpreters to be trained and for an unbiased test of the
interpretability of the imagery.

During the third week in July, 1969, predetermined flight lines were
flown at each of the five selected test sites with the LIU equipment. Table
1 gives information on the three camera/filter configurations used during
these overflights. In addition to the four broadband Kodak Wratten filters,
which had been used in early studies (Table 1, Configuration 3), narrow
band-pass filters manufactured for the LIU camera were installed in sets of
four (Configurations 1 and 2, Table 1). Optimum aperture stops and process-
ing specifications were established by LIU personnel in order to provide
negatives on which corresponding images of grey scale targets have essentially
the same density and gamma in all spectral bands. Mounted on the same air-
craft and operating simultaneously with the multiband camera were two K-24
aerial cameras having focal lengths of approximately 7" and a 5" X 5" format.
In one of these cameras Aerial Ektachrome film, with an appropriate haze-cut-

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TABLE 1. 1969 4-LENS MULTIBAND PHOTOGRAPHY.

CONFIGURATION	FRAME SYMBOL	PEAK λ	@ $\frac{1}{2}$ TRANS.	% TRANS.
1	0	754.0	39.0	84
	L	553.0	45.0	52
	M	682.5	31.0	80
	Q	848.5	38.0	70
2	J	581.0	49.0	46
	K	626.2	50.0	46
	P	799.0	34.5	68
	N	722.5	33.5	80
3	H - Kodak Wratten 89B			
	G - Kodak Wratten 25 with IR cut-off (301)			
	F - Kodak Wratten 58 with IR cut-off (301)			
	E - Kodak Wratten 47B with IR cut-off (301)			

ting filter, was exposed. The other camera contained Ektachrome Infrared film with a 15 filter. Efforts were made to bore-sight mount these two cameras in such a way as to coincide closely with the optical axis of the multiband camera system.

In addition to the LIU multiband experiment, two other tests were carried out in 1969 by members of the FRSL in the Phoenix area; one of these studies is continuing at present. On March 12, 1969, the Apollo 9 astronauts, in conjunction with the S065 multiband experiment, photographed the Phoenix test site. Results derived from the analysis of this imagery have been recorded in the report entitled "An Evaluation of Earth Resources Using Apollo 9 Photography" (Colwell et al., 1969). Concurrent with the Apollo 9 mission, ultra-high altitude aerial photography was obtained of the principal study areas in Phoenix, and these flights have been recurring up to the present time at approximately monthly intervals. These "high flights" are providing a means by which changes in image tonal characteristics due to seasonal variations in cultivated fields can be closely correlated with crop types. A special report submitted to NASA, entitled "Analysis of Earth Resources on Sequential High Altitude Multiband Photography" (Pettinger, 1969), summarizes results obtained during the 1969 growing season.

COLLECTION OF GROUND TRUTH CONCURRENT WITH AIRCRAFT OPERATIONS

For various calibrated color panels placed on the ground at each test site, and also for selected spots where specific vegetation, soil and rock types were exposed to the aerial view, spectroradiometric measurements were made by LIU and FRSL personnel during the time of image acquisition. In addition, the spectral composition of incident sunlight was measured. These data were used to aid in the exposing, processing, and reprocessing (i.e., calibration) of the multiband imagery.

Environmental ground truth information was collected in each test site by FRSL personnel. For example, for each field within the agricultural areas, crop category, crop type and crop condition were recorded. In the Phoenix area, we began collecting crop data as early as March 1969 and have been collecting it on an approximate monthly basis ever since.

DELIVERY OF IMAGERY FROM LIU TO THE UNIVERSITY OF CALIFORNIA AT BERKELEY (UCB)

All multiband photography obtained during the summer of 1969 was precision-processed in accordance with current state-of-the-art techniques to produce the highest quality negatives possible. The negatives were examined by LIU personnel and exact specifications given in terms of gamma, "D" max. and "D" min., for making positive transparencies to be used in the interpretation tests (see Table 2). The Aerial Ektachrome and Ekta Aero Infrared films were processed to positive transparencies at the LIU lab and were temporarily retained by that facility.

According to the original contract schedule, duplicate positive B/W transparencies were to be delivered from LIU to UCB no later than August 27, 1969. Image enhancement and interpretation testing was to follow immediately. However, assistance in making the positive transparencies was requested by LIU; hence the original negatives were sent on October 3, 1969, to NASA/MSC, where positive transparencies were made on a Niagara printer. An additional delay in making the positive transparencies was encountered at the NASA/MSC photo lab due to an unavoidably heavy workload associated with the Apollo 11 mission. The FRSL received one set of positive transparencies on February 19, 1970, a date six months later than originally anticipated. Consequently, a request to extend the completion date for this contract was made. The revised contract completion date was then designated December 31, 1970.

TABLE 2.   INSTRUCTIONS FOR PRINTING POSITIVE TRANSPARENCIES.

1.   Process the positive to a gamma of 2.0 $\pm$ .10.

2.   Basic exposure must be such that the step marked with an
     arrow at the beginning of each roll is reproduced in the
     positive with a density of .80 $\pm$ .05.

3.   The exposure of each record must be individually adjusted
     by plotting neutral density filters (tabulated below) in
     the printing system in such a way as to hold back the
     proper amount of light from each record.

ROLL #	FRAME #	RECORD 1	RECORD 2	RECORD 3	RECORD 4
ON-22	1-98	.40	.90	.90	0
	99-121	.40	.70	.90	.50
	122-153	.30	.80	.80	.80
ON-23	1-61	.40	.60	.60	.50
	62-137	0	.50	.60	.20
	138-167	.40	.40	.40	.40
	168-229	.20	.80	.80	0
ON-24	1-19	0	.20	.20	0
	20-89	0	0	0	0
	90-109	0	.20	.20	0
	110-121	0	0	0	0
	122-135	0	.20	.20	0
ON-25	1-14	.30	.70	.70	0
	15-30	1.10	1.10	1.30	0
	31-120	.50	.50	.60	.80
	121-176	1.10	1.00	1.10	1.20
ON-26	1-82	0	.50	.50	0
	83-111	.80	.80	1.10	1.30

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EXPERIMENTAL DESIGN

The availability of (1) high quality multiband photography, (2) comprehensive ground truth information collected at the time of the overflights, and (3) a large group of skilled and semi-skilled photo interpreters here at the FRSL provided the components for quantitative tests to be run on the relative interpretability of various image types and, in one case, interpreter performance as it relates to skill.

Photo interpretation test results were derived from various types of single-band and multiband imagery for each of several resource inventory problems at five different test sites. A complete description of the individual interpretation tests performed on imagery of a particular test site is presented in the following sections.

The results of the photo interpretation tests were expressed as both percent correct and percent commission error:

$$\text{Percent correct} = \frac{\text{number of correct interpretations of a resource type}}{\text{total number of a resource type present}} \times 100$$

$$\text{Percent commission error} = \frac{\text{number of incorrect interpretations of a resource type}}{\text{total number of a resource type indicated by the interpreter}} \times 100$$

In several instances the results were analyzed for the <u>total</u> resources of an area (e.g., total cropland, all trees by species, etc.). For these cases, test results were expressed only as percent correct.

Interpretation test results were analyzed using a one-way analysis of variance (ANOVA). The statistical model used was

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$$X_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

i = 1,2,...,k (groups, i.e., image types)

j = 1,2,...,n (replications, i.e., photo
interpreters),

where μ is the general mean, α is the main treatment or image type effect, and ε_{ij} is the experimental error.

Individual photo interpreters were <u>randomly</u> selected from a pool of 15 persons employed by the FRSL and assigned to one of the image type groups being tested (see Table 3). For the Yosemite and Bucks Lake tests, however, the interpreters were subjectively pooled into groups so that the variation of interpreters' skill within each group would be as equal as possible. These groups were then randomly assigned to the image types being tested.

The hypotheses tested were:

$$H_0 : \alpha_i = 0$$

$$H_1 : \alpha_i > 0$$

In the event that the null hypothesis was accepted (i.e., the computed F ratio was less than the theoretical F ratio), it was concluded that differences between the image types' means were not statistically significant and hence the test results were not statistically ranked. However, if the null hypothesis was rejected (i.e., the computed F ratio was greater than the theoretical F ratio) it was concluded that there were statistically significant differences between the image types' means, and these means were then ranked using Duncan's new multiple range test (see Figure 2).

Duncan's new multiple range test is a comparison among treatment means,

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TABLE 3. SAMPLE TABLE OF INTERPRETER ASSIGNMENTS.

This sample table demonstrates how 15 photo interpreters
might be assigned to different image type groups (Pan-25,
Infrared Ektachrome, Ektachrome, Enhancement 1, Enhancement
2) for testing purposes. The group means (i.e., $\bar{X}25$, $\bar{X}IRE$,
etc.) are then compared with the overall mean by analysis of
variance.

IMAGE TYPE REPLICATION	PAN-25	EKTA AERO IR	AERIAL EKTACHROME	ENHAN 1	ENHAN 2
1	X15	X3	X12	X1	X10
2	X6	X7	X14	X13	X3
3	X9	X4	X5	X11	X8
	$\bar{X}25$	$\bar{X}IRE$	$\bar{X}E$	$\bar{X}\#1$	$\bar{X}\#2$

```
REMARK:Q.E.I.V. PERCENT CORRECT ALL CROP

ENTER NO. OF GROUPS: 5
ENTER IN ORDER THE NO. OF OBSERVATIONS IN EACH GROUP:
3
3
3
3
3

TAPE(0) OR KEYBOARD(1) INPUT? 1

67.7 69.2 64.7
77.4 74.4 65.4
79.7 80.4 71.4
64.7 75.9 72.9
81.2 77.4 76.7


NO. IN GROUP           MEAN                STAND. DEV.
+.00003             +.6719999E+02          +.2291377E+01      IR - 25
+.00003             +.7240000E+02          +.6244910E+01      Aerial Ek
+.00003             +.7716666E+02          +.5006299E+01      Ek Aero IR
+.00003             +.7116666E+02          +.5797735E+01      Enh - A
+.00003             +.7843333E+02          +.2421615E+01      Enh - B

DEGREES OF FREEDOM
          BETWEEN              WITHIN             TOTAL
          +.00004             +.00010            +.00014

SUM OF SQUARES
       BETWEEN                  WITHIN                  TOTAL
+.2516089E+03           +.2175806E+03           +.4691895E+03

MEAN SQUARE
       BETWEEN                  WITHIN
+.6290223E+02           +.2175806E+02

F RATIO
+.2890985E+01
```

Figure 2. This computer printout example shows the ANOVA calculations made for
          "PERCENT CORRECT ALL CROP" from the Imperial Valley test results. All
          ANOVA calculations were made in the "in-house" computer at the FRSL.
          Note that the computed F ratio --2.89-- is greater than the theoretical
          F ratio --2.61-- for 4, 10 degrees of freedom at the .10 significance
          level. It was concluded that the above means were statistically
          different, and they were subsequently ranked using the Duncan's new
          multiple range test.

particularly nonindependent comparisons. The procedure for this test is as follows:

    1. Determine $S_{\bar{X}} = \sqrt{\text{mean square error}/n}$

    2. From the table of Significant Studentized Range, extract "p"--the significant studentized ranges or SSR--applicable to the number of means to be compared at the desired protection level. For example, if four means are to be involved in a comparison, three values will be taken from the table.

    3. Compute the least significant ranges (LSR):

$$LSR = S_{\bar{X}} \times SSR$$

    4. Rank the means to be compared in increasing order.

    5. Test the differences of the ranked means in the following order: largest minus smallest, largest minus second smallest,..., largest minus second largest; and so on down to second smallest minus smallest. If these differences prove to be larger than their respective LSR value, the differences are declared significant and can be ranked accordingly (Steel and Torrie, 1960).

In addition to the ANOVA testing, a statistical test was carried out for the Imperial Valley test site to compare the test results of two groups of photo interpreters. Group 1 consisted of three interpreters randomly selected from the 15-man pool. Group 2 was comprised of those three interpreters selected from the remainder of the pool which were considered the most proficient at interpreting agricultural phenomena on remote sensing imagery. Both groups were given identical imagery taken from the agricultural area at Imperial Valley and the groups' means for "percent correct all cropland" were compared.

The hypothesis tested was:

$$H_0 : \mu_1 - \mu_2 = 0$$

$$H_1 : \mu_1 - \mu_2 < 0$$

The test statistic was:

$$t = \frac{\bar{D} - (\mu_1 - \mu_2)}{S_{\bar{D}}},$$

where $\bar{D} = \bar{X}_1 - \bar{X}_2$, and $S_{\bar{D}}$ is calculated from the pooled Group 1 and Group 2 variances.

If the null hypothesis is accepted (i.e., the computed "t" value is greater than the theoretical "t" value), it would be concluded that selecting the most proficient interpreters was unnecessary, in that the interpretation results were not significantly better.

If the null hypothesis is rejected (i.e., the computed "t" value is less than the theoretical "t" value) it would be concluded that the group of picked skilled interpreters was better able to estimate the desired parameters on the imagery than the group of randomly selected interpreters.

The significance level for hypothesis testing was chosen at 10 percent (0.1) and the protection level for the Duncan's new multiple range test was chosen at 90 percent. Generally speaking, this is a somewhat high significance level at which to test hypotheses, and the occurrence of Type I error (rejecting the null hypothesis when it is true) is accordingly high. However, it was decided that it would be more desirable to minimize the occurrence of Type II error (accepting the null hypothesis when the alternative hypothesis is true) in order to maximize the power of the test. In this way the failure to recognize significant differences between means would be minimized at the expense of declaring some homogeneous means significantly different.

The optical density data measured with the aid of a densitometer were analyzed at significance and protection levels of 5 percent and 95 percent,

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respectively. Since the variation in the densitometer readings for a partic-
ular crop is much less than the variation of human photo interpretation test
results, the occurrence of Type I error was reduced and the power of the test
still remained at an acceptable level.

INTERPRETATION TESTS AND TEST RESULTS

FOREST RESOURCES

Yosemite Valley Test Site

Test Set-up. In July 1969, the LIU group obtained multiband photography
of one of the forestry study areas--Yosemite Valley, California. This area was
selected for testing multiband photographic techniques as applied to a common
forest inventory problem, tree species and tree type identification. The
floor of the valley is an ideal site for testing purposes since it is a simple
forest environment consisting of level terrain, deep rich alluvial soils and a
mixed conifer forest cover type. Large numbers of four major tree species (see
Figure 3) are dispersed throughout the area in dense mixed stands: ponderosa
pine (Pinus ponderosa), California incense cedar (Libocedrus decurrens),
California black oak (Quercus kelloggii), and black cottonwood (Populus tricho-
carpa).

Five sets of images, illustrated in Figures 4 through 8, were selected
for testing--two sets of single-band photos (IR-301+25 and IR-89B) and three
sets of multiband photos (Ekta Aero Infrared, Enhancement X and Enhancement
Y). Enhancement X was made by optically combining three narrow band-pass
film/filter combinations. Three images with peak transmission at wavelengths
of 553 nanometers, 682 nanometers and 754 nanometers were projected through red,
blue and green filters, respectively. Enhancement Y (broad band) was made by

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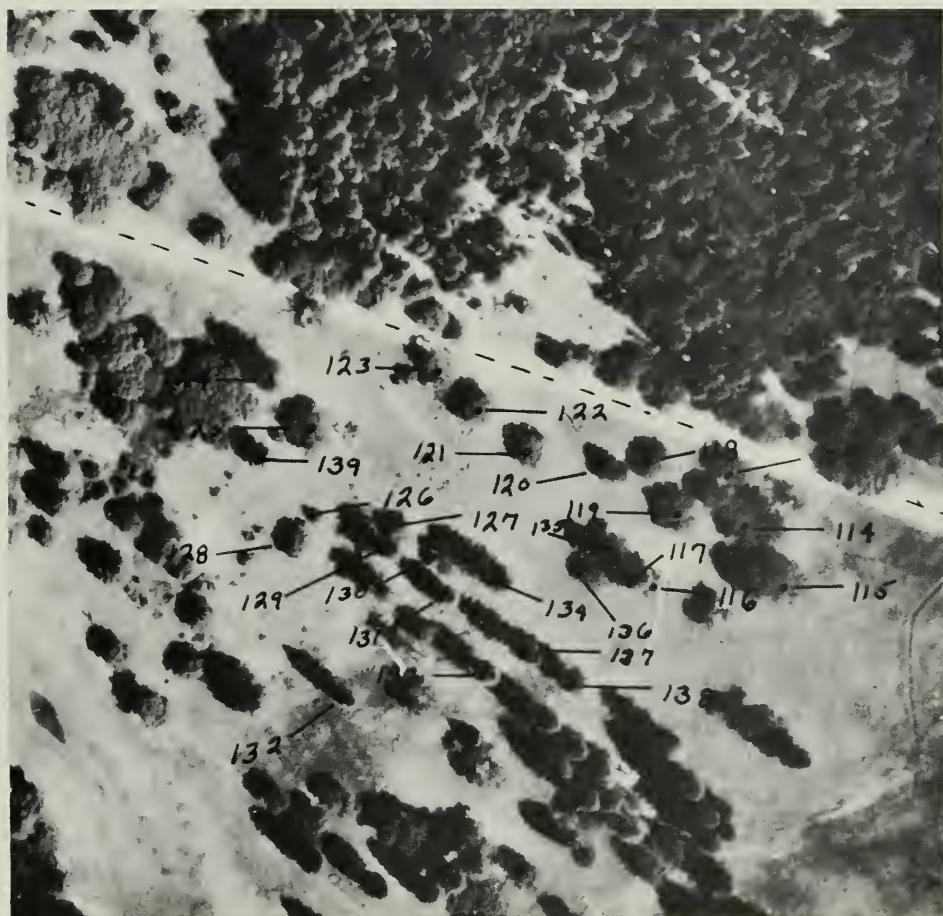
Figure 3.   A portion of the ground data for the Yosemite Valley, California, study area is shown here. Individual trees, correctly identified as to species by ground observation, are located by arrow and number. A total population of 277 trees was selected for study; 27 trees are shown here:

Ponderosa pine: 117, 124, 129, 131, 132, 133, 134, 137, 138, 139

California black oak: 113, 114, 115, 116, 118, 119, 120, 121, 122, 123, 125, 126, 127, 128, 130, 135, 136

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Figure 4. IR-301+25 imagery and test results for Yosemite Valley, California, study area. P: ponderosa pine, I: incense cedar, O: black oak, C: cottonwood, CF: conifer. HD: hardwood.

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	35	14	11	1	61	26
I	4	11	3		18	7
O	12	9	38	4	63	25
C	2	5	12	2	21	19
TOTAL TREES	53	39	64	7	163	
OMIS. ERROR	18	28	26	5		77

I. R.	G.D. CF	HD.	TOTAL SAMPLE	COM. ERROR
CF.	64	15	79	15
HD.	28	56	84	28
TOTAL TREES	92	71	163	
OMIS. ERROR	28	15		43

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	32	15	5	3	55	23
I	7	8	5		20	12
O	7	8	38	2	55	17
C	6	7	15	1	29	28
TOTAL TREES	52	38	63	6	159	
OMIS. ERROR	20	30	25	5		80

I. R.	G.D. CF	HD.	TOTAL SAMPLE	COM. ERROR
CF.	62	13	75	13
HD.	28	56	84	28
TOTAL TREES	90	69	159	
OMIS. ERROR	28	13		41

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	34	10	9		53	19
I	9	15	4	2	30	15
O	5	10	38	1	54	16
C	4	4	14	3	25	22
TOTAL TREES	52	39	65	6	162	
OMIS. ERROR	18	24	27	3		72

I. R.	G.D. CF	HD.	TOTAL SAMPLE	COM. ERROR
CF.	68	15	83	15
HD.	23	56	79	23
TOTAL TREES	91	71	162	
OMIS. ERROR	23	15		38

Figure 4 (cont.)

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	22	7	11	1	41	19
I	7	9	11	6	33	24
O	4	7	23	2	36	13
C	6	3	4	3	16	13
TOTAL TREES	39	26	49	12	126	
OMIS. ERROR	17	17	26	9		69

I.R.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	45	29	74	29
HD.	20	32	52	20
TOTAL TREES	65	61	126	
OMIS. ERROR	20	29		49

INTERPRETER # 5

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	21	13	10	3	47	26
I	4	3	3		10	7
O	8	8	30	5	51	21
C	6	3	5	3	17	14
TOTAL TREES	39	27	48	11	125	
OMIS. ERROR	18	24	18	8		68

I.R.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	41	16	57	16
HD.	25	43	68	25
TOTAL TREES	66	59	125	
OMIS. ERROR	25	16		41

P: ponderosa pine, I: incense cedar, O: California black oak, C: cottonwood, CF: conifer, HD: hardwood.

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Figure 5. IR-89B imagery and test results for Yosemite Valley, California, study area. P: ponderosa pine, I: incense cedar, 0: California black oak, C: cotton-wood. CF: conifer, HD: hardwood.

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	18	11	6		35	17
I	26	22	13	3	64	42
O	3	1	39	2	45	6
C	5	4	8	2	19	17
TOTAL TREES	52	38	66	7	163	
OMIS. ERROR	34	16	27	5		82

INT.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	77	22	99	22
HD.	13	51	64	13
TOTAL TREES	90	73	163	
OMIS. ERROR	13	22		35

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	29	6	8		43	14
I	9	14	4		27	13
O	10	18	48	2	78	30
C	5	1	4	5	15	10
TOTAL TREES	53	39	64	7	163	
OMIS. ERROR	24	25	16	2		67

INT.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	58	12	70	12
HD.	34	59	93	34
TOTAL TREES	92	71	163	
OMIS. ERROR	34	12		46

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	15	7	11	1	34	19
I	12	5	12	2	31	26
O	3	9	18	3	33	15
C	6	4	5	6	21	15
TOTAL TREES	36	25	46	12	119	
OMIS. ERROR	21	20	28	6		75

INT.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	39	26	65	26
HD.	22	32	54	22
TOTAL TREES	61	58	119	
OMIS. ERROR	22	26		48

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Figure 5. (cont.)

INTERPRETER # 5

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	26	4	8	3	41	15
I	3	16	1	1	21	5
O	9	7	39	7	62	23
C			1	1	2	1
TOTAL TREES	38	27	49	12	126	
OMIS. ERROR	12	11	10	11		44

R.I.	G.D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	49	13	62	13
HD.	16	48	64	16
TOTAL TREES	65	61	126	
OMIS. ERROR	16	13		29

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	18	14	2	2	36	18
I	7	3	1	5	11	8
O	2	3	24	5	34	10
C	9	5	21	4	39	55
TOTAL TREES	36	25	48	11	120	
OMIS. ERROR	18	22	24	7		71

R.I.	G.D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	42	5	47	5
HD.	19	54	73	19
TOTAL TREES	61	59	120	
OMIS. ERROR	19	5		24

P: ponderosa pine, I: incense cedar, O: California black oak, C: cottonwood, CF: conifer, HD: hardwood.

Figure 6. Ekta Aero IR imagery and test results for Yosemite Valley, California, study area. P: ponderosa pine, I: incense cedar, 0: California black oak, C: cottonwood, CF: conifer, HD: hardwood
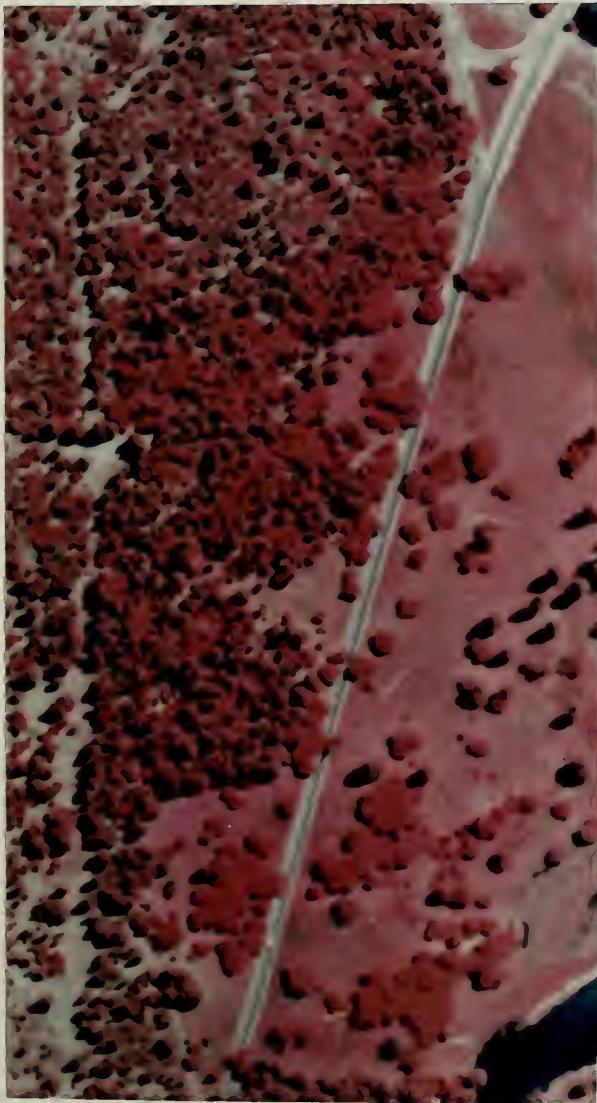
INTERPRETER #1

INTERPRETER RESULTS	\ GROUND DATA	P	I	O	C	TOTAL SAMPLE	COM. ERROR
P		24	15	2	3	44	20
I		4		2	2	8	6
O		16	24	25	4	69	44
C		7	12	30	8	57	49
TOTAL TREES		51	53	59	15	178	
OMIS. ERROR		27	51	34	7	119	119

I.R.	\ G.D.	CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.		45	7	52	7
HD.		59	67	126	59
TOTAL TREES		104	74	178	
OMIS. ERROR		59	7		66

INTERPRETER #3

INTERPRETER RESULTS	\ GROUND DATA	P	I	O	C	TOTAL SAMPLE	COM. ERROR
P		38	40	7	1	86	48
I		1	2			3	1
O		11	11	45	12	79	34
C		1	2	7	2	12	10
TOTAL TREES		51	55	59	15	180	
OMIS. ERROR		13	53	14	13		93

I.R.	\ G.D.	CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.		81	8	89	8
HD.		25	66	91	25
TOTAL TREES		106	74	180	
OMIS. ERROR		25	8		33

INTERPRETER #2

INTERPRETER RESULTS	\ GROUND DATA	P	I	O	C	TOTAL SAMPLE	COM. ERROR
P		17	34	2	1	54	37
I		31	11	4	2	48	37
O		4	6	44	9	63	19
C		4	10	3		17	14
TOTAL TREES		52	55	60	15	182	
OMIS. ERROR		35	44	16	12	107	

I.R.	\ G.D.	CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.		93	9	102	9
HD.		14	66	80	14
TOTAL TREES		107	75	182	
OMIS. ERROR		14	9		23

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Figure 6. (cont.) P: ponderosa pine, I: incense cedar, O: California black oak, C: cottonwood, CF: conifer, HD: hardwood

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	23	8		4	35	12
I	5	5	5	2	17	12
O	4	7	40	4	55	15
C	6	7	4	5	22	17
TOTAL TREES	38	27	49	15	129	
OMIS. ERROR	15	22	9	10		56

R	G.D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	41	11	52	11
HD.	24	53	77	24
TOTAL TREES	65	64	129	
OMIS. ERROR	24	11		35

INTERPRETER # 5

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	19	6		2	27	8
I	9	11	1	3	24	13
O	9	9	40	8	66	26
C	3	1	8	2	14	12
TOTAL TREES	40	27	49	15	131	
OMIS. ERROR	21	16	9	13		59

R	G.D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	45	6	51	6
HD.	22	58	80	22
TOTAL TREES	67	64	131	
OMIS. ERROR	22	6		28

INTERPRETER # 6

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	20	4	3		27	7
I	11	12	1		24	12
O	4	3	40	11	58	18
C	6	6	6	1	19	18
TOTAL TREES	41	25	50	12	128	
OMIS. ERROR	21	13	10	11		55

| R	G.D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	47	4	51	4
HD.	19	58	77	19
TOTAL TREES	66	62	128	
OMIS. ERROR	19	4		23

Figure 7. Enhancement X imagery and test results for Yosemite Valley, California, study area. P: ponderosa pine, I: incense cedar, 0: black oak, C: cottonwood, CF: conifer. HD: hardwood

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	20	18	8	2	48	28
I	27	32	13	2	74	42
O	3	4	31	7	45	14
C	2	1	11	4	18	14
TOTAL TREES	52	55	63	15	185	
OMIS. ERROR	32	23	32	11		98

INTERPRETER RESULTS	G.D. CF	HD	TOTAL SAMPLE	COM. ERROR
CF	97	25	122	25
HD	10	53	63	10
TOTAL TREES	107	78	185	
OMIS. ERROR	10	25		35
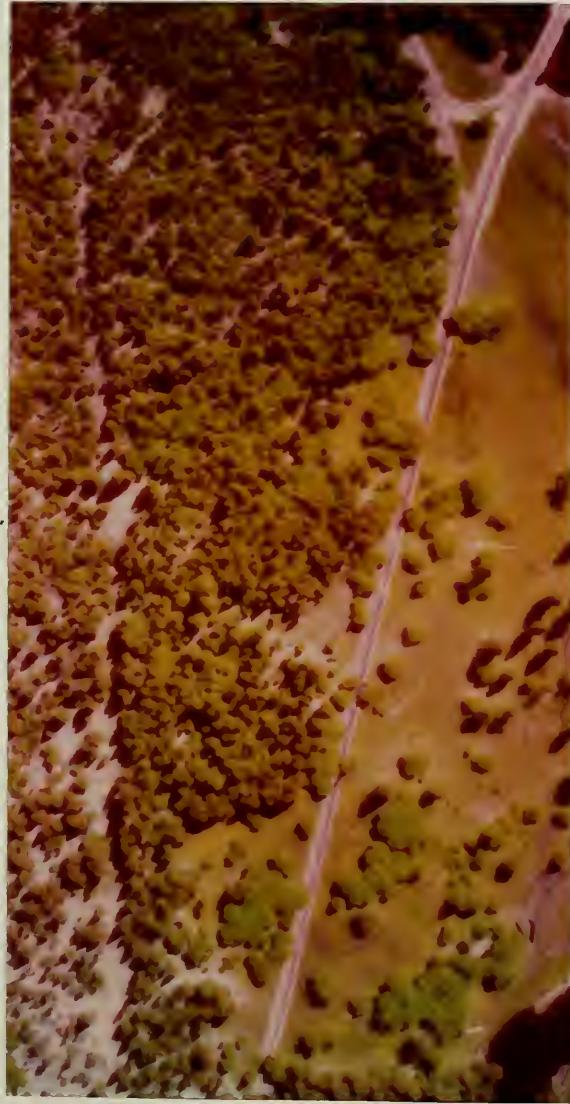
INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	29	38	4		71	42
I	18	5	3	5	26	21
O	2	1	37	5	45	8
C	3	9	18	8	38	30
TOTAL TREES	52	53	62	13	180	
OMIS. ERROR	23	48	25	5		101

INTERPRETER RESULTS	G.D. CF	HD	TOTAL SAMPLE	COM. ERROR
CF	90	7	97	7
HD	15	68	83	15
TOTAL TREES	105	75	180	
OMIS. ERROR	15	7		22

INTERPRETER #3

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	26	16	4	1	47	21
I	10	5	1		16	11
O	2	1	32	14	49	17
C	1	4	12	0	17	17
TOTAL TREES	39	26	49	15	129	
OMIS. ERROR	13	21	17	15		66

INTERPRETER RESULTS	G.D. CF	HD	TOTAL SAMPLE	COM. ERROR
CF	57	6	63	6
HD	8	58	66	8
TOTAL TREES	65	64	129	
OMIS. ERROR	8	6		14

Figure 7. (cont.)

INTERPRETER # 5

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	31	13	7	2	53	22
I	5	12	2		19	7
O	2	1	33	6	42	9
C	2		6	7	15	8
TOTAL TREES	40	26	48	15	129	
OMIS. ERROR	9	14	15	8		46

I. R.	G. D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	61	11	72	11
HD.	5	52	57	5
TOTAL TREES	66	63	129	
OMIS. ERROR	5	11		16

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	P	I	O	C		
P	27	10	2	1	40	13
I	4	12	1		17	5
O	2	2	33	6	43	10
C	7	2	11	8	28	20
TOTAL TREES	40	26	47	15	128	
OMIS. ERROR	13	14	14	7		48

I. R.	G. D.		TOTAL SAMPLE	COM. ERROR
	CF.	HD.		
CF.	53	4	57	4
HD.	13	58	71	13
TOTAL TREES	66	62	128	
OMIS. ERROR	13	4		17

P: ponderosa pine, I: incense cedar, O: California black oak, C: cottonwood, CF: conifer, HD: hardwood

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Figure 8. Enhancement Y imagery and test results for Yosemite Valley, California, study area. P: ponderosa pine, I: incense cedar, O: black oak, C: cottonwood, CF: conifer, HD: hardwood

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE TREES	COM. ERROR
P	42	22	8	2	74	32
I	10	17	4		31	14
O	3	14	37	3	57	20
C	3	2	10	5	20	15
TOTAL TREES	58	55	59	10	182	
OMIS. ERROR	16	38	22	5	81	

I.R.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	91	14	105	14
HD.	22	55	77	22
TOTAL TREES	113	69	182	
OMIS. ERROR	22	14	36	

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE TREES	COM. ERROR
P	35	29	3	2	67	32
I	9	12	6	2	29	17
O	8	10	39	9	66	27
C	5	4	11	1	21	20
TOTAL TREES	57	55	59	12	183	
OMIS. ERROR	22	43	20	11	96	

I.R.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	85	11	96	11
HD.	27	60	87	27
TOTAL TREES	112	71	183	
OMIS. ERROR	27	11	38	

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE TREES	COM. ERROR
P	29	13	6	1	49	20
I	1	7	1		9	2
O	3	14	37	6	60	23
C	13	18	9	4	44	40
TOTAL TREES	46	52	53	11	162	
OMIS. ERROR	17	45	16	7	85	

I.R.	G.D. CF.	HD.	TOTAL SAMPLE	COM. ERROR
CF.	60	8	68	8
HD.	48	56	104	48
TOTAL TREES	108	64	162	
OMIS. ERROR	48	8	56	

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Figure 8. (cont.) P: ponderosa pine, I: incense cedar; O: black oak, C: cottonwood, CF: conifer, HD: hardwood.

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	10	2	4	2	18	8
I	16	14	14	2	46	32
O	4	6	23	3	36	13
C	5	4	4	5	18	13
TOTAL TREES	35	26	45	12	118	
OMIS. ERROR	25	12	22	7		66

R̄.I	G.D. CF	HD.	TOTAL SAMPLE	COM. ERROR
CF.	42	22	64	22
HD.	19	35	54	19
TOTAL TREES	61	57	118	
OMIS. ERROR	19	22		41

INTERPRETER # 6

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	26	14	7	1	48	22
I	5	8	1	1	15	7
O	1	2	31	6	40	9
C	3	2	5	4	14	10
TOTAL TREES	35	26	44	12	117	
OMIS. ERROR	9	18	13	8		48

R̄.I	G.D. CF	HD.	TOTAL SAMPLE	COM. ERROR
CF.	53	10	63	10
HD.	8	46	54	8
TOTAL TREES	61	56	117	
OMIS. ERROR	8	10		18

INTERPRETER # 5

INTERPRETER RESULTS	GROUND DATA P	I	O	C	TOTAL SAMPLE	COM. ERROR
P	17	9	2	2	30	13
I	15	14	3	1	33	19
O	2	1	34	4	41	7
C	1	2	6	5	14	9
TOTAL TREES	35	26	45	12	118	
OMIS. ERROR	18	12	11	7		48

R̄.I	G.D. CF	HD.	TOTAL SAMPLE	COM. ERROR
CF.	55	8	63	8
HD.	6	49	55	6
TOTAL TREES	61	57	118	
OMIS. ERROR	6	8		14

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TABLE 4. YOSEMITE VALLEY, CALIFORNIA: IMAGE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT AND MEAN PERCENT COMMISSION ERROR FOR TREE SPECIES IDENTIFICATION.

TREE SPECIES	RANKED IMAGES	PERCENT CORRECT	SIG. DIF.(0.1)	HOMO. GROUP(S)	RANKED IMAGES	% COMM. ERROR	SIG. DIF.(0.1)	HOMO. GROUP(S)
All trees by species	Enh Y	51.5	No					
	Ek Aero IR	51.3						
	IR-301+25	50.2						
	Enh X	50.1						
	IR-89B	46.2						
Ponderosa Pine	Enh X	61.9	No		Ek Aero IR	43.5	No	
	IR-301+25	60.5			IR-301+25	44.2		
	Enh Y	57.3			Enh Y	44.9		
	Ek Aero IR	53.0			Enh X	47.1		
	IR-89B	45.4			IR-89B	47.2		
Incense Cedar	Enh X	35.8	No		Enh Y	51.8	No	
	Enh Y	34.0			Enh X	55.3		
	IR-89B	31.2			IR-301+25	58.3		
	IR-301+25	27.0			Ek Aero IR	59.0		
	Ek Aero IR	21.6			IR-89B	67.1		
California Black Oak	Ek Aero IR	78.6	Yes		Enh X	26.2	No	
	Enh Y	65.1			IR-89B	31.6		
	Enh X	61.6			Enh Y	31.8		
	IR-301+25	57.2			Ek Aero IR	34.6		
	IR-89B	55.8			IR-301+25	35.5		
Black Cottonwood	Ek Aero IR	51.4	No		Enh X	76.3	No	
	IR-89B	41.7			Enh Y	78.8		
	Enh Y	32.9			IR-89B	81.0		
	Enh X	25.9			Ek Aero IR	86.6		
	IR-301+25	25.1			IR-301+25	87.7		

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cottonwood. Consequently, it is frequently impossible to discriminate one con-

ifer from another or one hardwood from another based on comparisons of tone

signature alone. However, the conifer and hardwood groups have very distinct

and different spectral characteristics, and these differences can be exploited

with properly selected and enhanced multiband photography.

The interpretation results presented in Table 5 relating to tree type dis-

crimination indicate that in four out of five tests, there were significant dif-

ferences in the interpretability of the five kinds of test imagery. Specifically,

Enhancement "X", the narrow band enhancement, gave significantly better percent

correct identification results for coniferous trees than the remaining four kinds

of imagery. The test also showed that Enhancement "X" was significantly better

for conifer identification than the two single band images in terms of percent

commission error but not different from the multiband images. For hardwood

identification, there were no differences between image types in terms of per-

cent correct, but Enhancement X was superior to Enhancement Y, IR-89B and

IR-301+25 (but similar to Ekta Aero IR) in terms of percent commission error.

When all trees in the population were analyzed in terms of correct identifica-

tion, Enhancement X was again superior to Enhancement Y, IR-89B and IR-301+25,

but not to Ekta Aero Infrared. In addition, in every case except one (conifers,

percent correct) the two types of single band imagery ranked lowest for tree

type identification; and Enhancement X, in all cases except two (conifers, percent

commission error, and hardwoods, percent correct) ranked highest for this purpose.

Therefore, it is possible to conclude from these data that if our task

is to select the best type of imagery for typing forest vegetation (i.e., hard-

woods vs. conifers) in their midsummer state, we could justify choosing narrow

band multiband imagery of the type used in this experiment since it provided as

much information as the other types of broad-band multiband imagery tested, and,

in some instances, was superior to all other types of test imagery.

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INTERPRETER #1

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	37	1					38	1
2		20	1	1			22	2
3		3	34	3	1		41	7
4		1		10			11	1
5					12		12	0
6						7	7	0
TOTAL PLOTS	37	25	35	14	13	7	131	
OMIS. ERROR	0	5	1	4	1	0		11

INTERPRETER #2

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	41	2					43	2
2		19	1	1			21	2
3			33	7			40	7
4			1	5			6	1
5					14		14	0
6						7	7	0
TOTAL PLOTS	41	21	35	13	14	7	131	
OMIS. ERROR	0	2	2	8	0	0		12
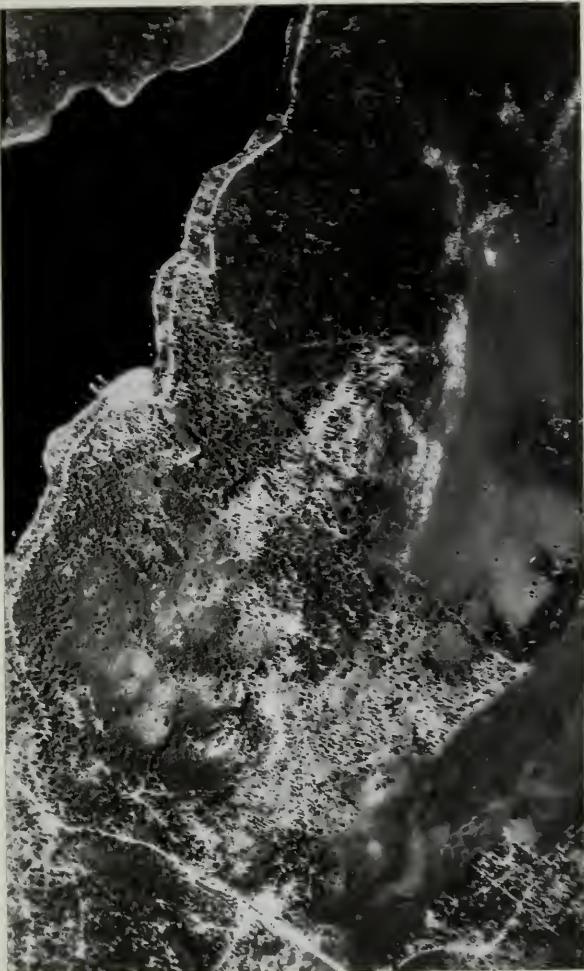
Figure 9. IR-301+25 imagery and test results for the Bucks Lake, California, study area.

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INTERPRETER # 4

	GROUND DATA						TOTAL SAMPLE	COM. ERROR
INTERPRETER RESULTS	1	2	3	4	5	6		
1	21						21	0
2	3	10	1				14	4
3			18	3			21	3
4		2		29	1		32	3
5				4	15		19	4
6						2	2	0
TOTAL PLOTS	24	12	19	36	16	2	109	
OMIS. ERROR	3	2	1	7	1	0		14

INTERPRETER # 3

|	GROUND DATA						TOTAL SAMPLE	COM. ERROR
INTERPRETER RESULTS	1	2	3	4	5	6		
1	17						17	0
2	5	13					18	5
3			15	4			19	4
4			4	32			36	4
5					17		17	0
6						1	1	0
TOTAL PLOTS	22	13	19	36	17	1	108	
OMIS. ERROR	5	0	4	4	0	0		13

Figure 9. (cont.)

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Figure 10. IR-89B imagery and test results for the Bucks Lake, California, study area.

INTERPRETER #1

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	37	3					40	3
2	1	18					20	2
3		2	36		5		43	7
4				9	1		10	1
5			1	5	5		11	6
6						7	7	0
TOTAL PLOTS	38	23	37	14	12	7	131	
OMIS. ERROR	1	5	1	5	7	0		19

INTERPRETER #2

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	37	4	2				43	6
2	2	16	2				20	4
3		2	28				30	2
4		1		13	2		16	3
5			2		11		13	2
6						8	8	0
TOTAL PLOTS	39	23	34	13	13	8	130	
OMIS. ERROR	2	7	6	0	2	0		17

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INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	23	3		1			27	4
2	1	7	3	4	1		16	9
3			16		5		21	5
4		1		32	1		34	2
5					10		10	0
6						1	1	0
TOTAL PLOTS	24	11	19	37	17	1	109	
OMIS. ERROR	1	4	3	5	7	0		20

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	27			1			31	4
2	3	6					9	3
3			21	3			24	3
4				32	1		33	1
5					10		10	0
6						2	2	0
TOTAL PLOTS	27	9	21	36	14	2	109	
OMIS. ERROR	0	3	0	4	4	0		11

Figure 10. (cont.)

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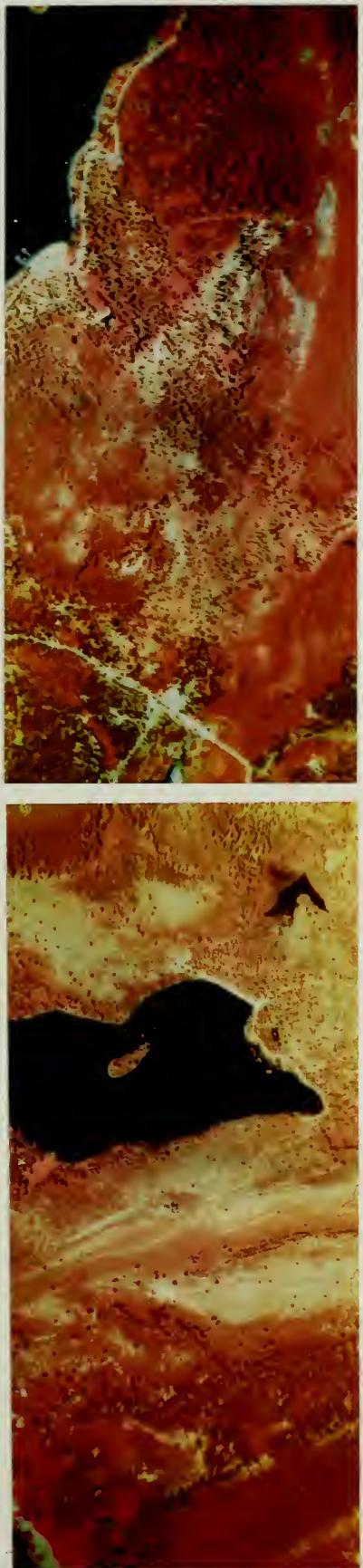
Figure 11. Enhancement 1 imagery and test results for the Bucks Lake, California, study area.

INTERPRETER # 1

		GROUND DATA						TOTAL SAMPLE	COM. ERROR
		1	2	3	4	5	6		
INTERPRETER RESULTS	1	28						28	0
	2	2	18	2				22	4
	3		3	29				32	3
	4				11			11	0
	5			1	1	10		12	2
	6						4	4	0
TOTAL PLOTS		30	21	32	12	10	4	109	
OMIS. ERROR		2	3	3	1	0	0		9

INTERPRETER # 2

		GROUND DATA						TOTAL SAMPLE	COM. ERROR
		1	2	3	4	5	6		
INTERPRETER RESULTS	1	29	1					30	1
	2	3	18	6	2			29	11
	3		2	20				22	2
	4			4	7			11	4
	5				1	9		10	1
	6						4	4	0
TOTAL PLOTS		32	21	30	10	9	4	106	
OMIS. ERROR		3	3	10	3	0	0		19

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	21	2					23	2
2		7		3			10	3
3			17	4			21	4
4	1			23			24	1
5					14		14	0
6						1	1	0
TOTAL PLOTS	22	9	17	30	14	1	93	
OMIS. ERROR	1	2	0	7	0	0		10

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	12						12	0
2	6	8					14	6
3	1		17	4			22	5
4	1	1		26			28	2
5	1			1	14		16	2
6						1	1	0
TOTAL PLOTS	21	9	17	31	14	1	93	
OMIS. ERROR	9	1	0	5	0	0		15
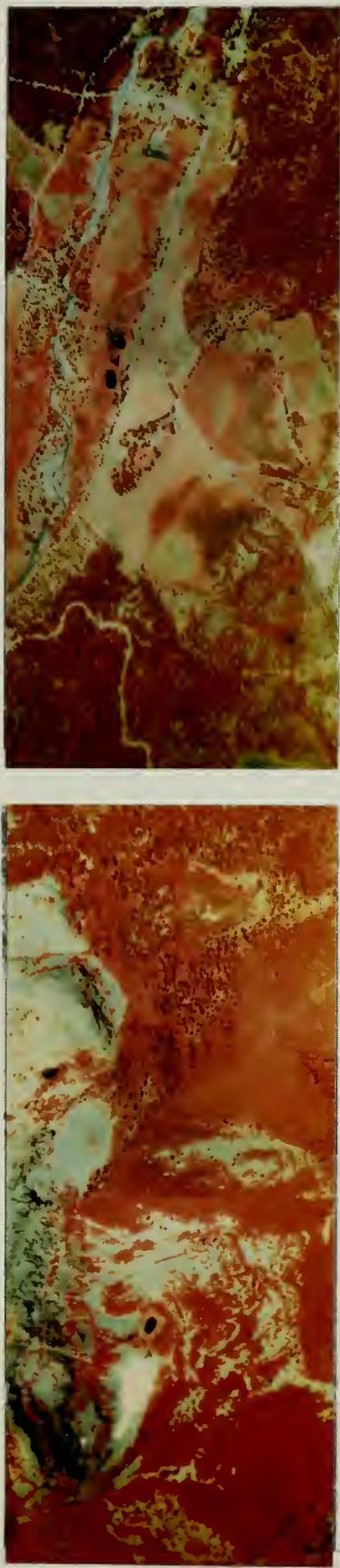
Figure 11. (cont.)

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	25		1				26	1
2	6	13					19	6
3		5	24	1			30	6
4		1	2	9	1		13	4
5		1	2	1	9		13	4
6						5	5	0
TOTAL PLOTS	31	20	29	11	10	5	106	
OMIS. ERROR	6	7	5	2	1	0		21

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	25		1				26	1
2	5	16	2				23	7
3	1	2	28				31	3
4		1	1	12			14	2
5			1		9		10	1
6						4	4	0
TOTAL PLOTS	31	19	33	12	9	4	108	
OMIS. ERROR	6	3	5	0	0	0		14

Figure 12. Enhancement 2 imagery and test results for the Bucks Lake, California, study area.

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	17						17	0
2	3	8					11	3
3			16				16	0
4	1			28	1		30	2
5		1	1	3	13		18	5
6						1	1	0
TOTAL PLOTS	21	9	17	31	14	1	93	
OMIS. ERROR	4	1	1	3	1	0		10

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	11						11	0
2	7	11					18	7
3	1		17				18	1
4		1		28			29	1
5				2	15		17	2
6						0	0	0
TOTAL PLOTS	19	12	17	30	15	0	93	
OMIS. ERROR	8	1	0	2	0	0		11

Figure 12. (cont.)

Figure 13. Enhancement 3 imagery and test results for the Bucks Lake, California, study area.

INTERPRETER # 1

					GROUND DATA						TOTAL SAMPLE	COM. ERROR
			1	**2**	**3**	**4**	**5**	**6**			
INTERPRETER RESULTS		**1**	32	5	1	1				39	7
		2		12	2					14	2
		3	1	3	19					23	4
		4		1	5	11				17	6
		5			2		10			12	2
		6						4		4	0
TOTAL PLOTS			33	21	29	12	10	4		109	21
OMIS. ERROR			1	9	10	1	0	0			

INTERPRETER # 2

					GROUND DATA						TOTAL SAMPLE	COM. ERROR
			1	**2**	**3**	**4**	**5**	**6**			
INTERPRETER RESULTS		**1**	31		1	1				33	2
		2	2	21	8					31	10
		3		2	16	2				20	4
		4		1		8				9	1
		5					9			9	0
		6						5		5	0
TOTAL PLOTS			33	24	25	11	9	5		107	17
OMIS. ERROR			2	3	9	3	0	0			

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INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	18		5				23	5
2	2	9		3			14	5
3			4	7			11	7
4			5	15			20	5
5			2	6	15		23	8
6						0	0	0
TOTAL PLOTS	20	9	16	31	15	0	91	
OMIS. ERROR	2	0	12	16	0	0		30

INTERPRETER # 4

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	16		4				20	4
2	4	9		1			14	5
3			10	7	2		19	9
4				10			10	0
5	1		2	11	12		26	14
6				1		1	2	1
TOTAL PLOTS	21	9	16	30	14	1	91	
OMIS. ERROR	5	0	6	20	2	0		33

Figure 13. (cont.)

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IR-301+25, and IR-301+58 images projected through red, green and blue filters, respectively. Enhancement 2 was made in a similar manner, with the following combination of bands and filters: IR-89B--blue filter; IR-301+25--red filter; and IR-301+58--green filter. Enhancement 3 was produced using IR-89B with a green filter, IR-301+25 with a red filter, and IR-301+58 with a blue filter.

A set of imagery consisted of two groups of two photos or transparencies each, i.e., four images per set. The two single-band image sets were viewed in print form, but the three multiband sets were viewed on a rear-projection viewer.

The interpreters were subjectively pooled into groups of four. These interpreter groups were then asked to examine one group of images from each of two sets, i.e., a different image group from two different sets. Hence, each image group was viewed by each interpreter group only once.

To test the accuracy with which the six forest resource types could be mapped, 240 rectangular areas, ranging from five to 20 acres in size, were chosen within the four photos which made up a set. A portion of these 240 areas were used as training examples; the remainder were examined and categorized by the interpreters (see Figure 14). The interpreters were asked to determine into which forest resource a particular area fell. (The mapping criteria for each resource type are listed in Table 6.) Guidelines were provided to the interpreters to assist them when the selected areas contained more than one resource type.

Test Results. In comparison with the other test areas, the test results from the Bucks Lake area were very good, i.e., high percent correct and low percent commission error (Table 7). This was due in part to the emphasis on identification of plant types and not individual species. In some cases this high accuracy was due more to the resource being categorized than to the

Figure 14. A portion of the Bucks Lake, California, study area is shown here.
Several "training" areas (circled) and test areas are indicated.
The correct classification of forest resource type within which
each test cell falls was done by on-the-ground observations. These
areas would be classed as follows:

189, 217, 232: medium-high density conifer; 188: low density
conifer; 193, 205, 224: brush; 209, 221, 235: meadow and
riparian vegetation; 190, 195, 199: bare soil or rock; 191:
water.

TABLE 6. FOREST RESOURCE TYPE MAPPING CRITERIA FOR BUCKS LAKE TEST SITE.

The following critera were used by photo interpreters to categorize the test areas as to resource type (five-acre minimum mapping area)

TYPE	DESCRIPTION
1	<u>Medium-high density conifer</u>: The percent crown cover of conifers, regardless of age or size, is 35 percent or more of the area.
2	<u>Low density conifer</u>: The percent crown cover of conifers, regardless of age or size, is more than five percent and less than 35 percent of the area.
3	<u>Brush-Dry Site Hardwood</u>: The percent ground cover of brush and/or dry site hardwoods is 60 percent or more of the area. However, types 1 and 2 take precedence over type 3.
4	<u>Meadow - Riparian Hardwoods</u>: Includes both wet and dry meadow sites. Types 1 and 2 take precedence over type 4.
5	<u>Bare Soil - Rock</u>: The percent bare soil and/or rock is 40 percent or more of the area. Types 1 and 2 take precedence over type 5.
6	<u>Water</u>: Any area of water greater than five acres.
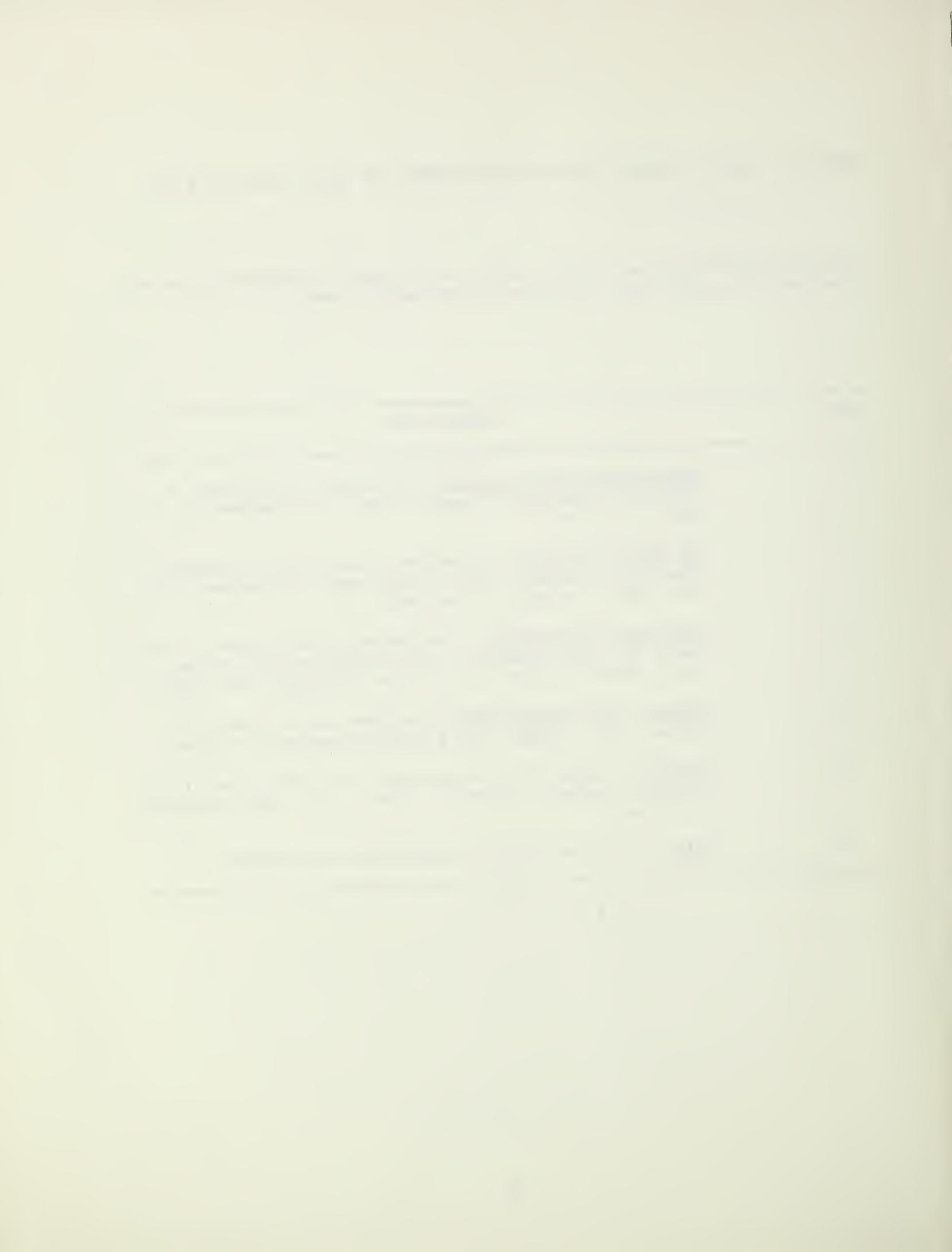
TABLE 7. BUCKS LAKE, CALIFORNIA: IMAGE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT AND MEAN PERCENT COMMISSION ERROR FOR FOREST RESOURCE DELINEATION TEST.

FOREST RESOURCE	RANKED IMAGES	PERCENT CORRECT	SIG. DIF.(0.1)	HOMO. GROUP(S)	RANKED IMAGES	% COMM. ERROR	SIG. DIF.(0.1)	HOMO. GROUPS
All types	IR-301+25	89.4	Yes					
	Enh 1	86.6						
	Enh 2	86.3						
	IR-89B	86.2						
	Enh 3	73.6						
Medium-high density conifer	IR-89B	97.0	No		IR-301+25	1.8	Yes	
	IR-301+25	91.2			Enh 2	1.9		
	Enh 3	89.3			Enh 1	3.0		
	Enh 1	84.2			IR-89B	12.8		
	Enh 2	75.0			Enh 3	17.3		
Low density conifer	IR-301+25	89.4	No		IR-301+25	19.1	No	
	Enh 3	86.2			IR-89B	29.9		
	Enh 1	84.5			Enh 3	30.5		
	Enh 2	82.5			Enh 2	32.1		
	IR-89B	70.3			Enh 1	32.8		
Brush - dry site hardwood	IR-301+25	91.2	Yes		Enh 2	12.0	Yes	
	IR-89B	91.2			IR-89B	13.0		
	Enh 2	90.8			Enh 1	15.0		
	Enh 1	89.6			IR-301+25	17.5		
	Enh 3	54.8			Enh 3	35.6		
Meadow - riparian hardwood	Enh 1	91.4	No		IR-89B	9.4	No	
	IR-89B	84.9			IR-301+25	11.6		
	Enh 2	79.0			Enh 1	11.7		
	IR-301+25	69.9			Enh 2	12.4		
	Enh 3	61.2			Enh 3	13.8		
Rock - bare soil	Enh 1	100.0	Yes		IR-301+25	5.3	No	
	Enh 2	95.7			Enh 1	9.8		
	IR-301+25	94.6			IR-89B	17.5		
	Enh 3	93.9			Enh 2	19.9		
	IR-89B	64.1			Enh 3	26.3		
Water	IR-301+25	100.0	No		IR-301+25	0.0	No	
	IR-89B	100.0			IR-89B	0.0		
	Enh 1	100.0			Enh 1	0.0		
	Enh 2	100.0			Enh 2	0.0		
	Enh 3	100.0			Enh 3	16.7		

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imagery type being used. This becomes clear when examining the test results by each resource type.

Discussion of Results.

(1) Medium-High Density Conifer and Low Density Conifer. Both of these resource types had high percent correct identification for each image type used, but for none of these types was the difference in test results statistically significant at the ten percent level. It would seem that these high accuracy levels are due to the high resolution of all the imagery tested, which makes individual conifers easily identified. In addition, there are no resource types in the Bucks Lake area which would be confused with the conifer type at this resolution. For example, large, tall hardwoods do not grow in extensive stands as do conifers but are found as riparian vegetation along stream banks or as isolated trees in brush fields. Thus a photo interpreter with a forestry background would be able to correctly categorize these two resource types with a high degree of success at the scale and resolution of the test photography regardless of the image type being used.

The higher commission error of the low density conifer when compared to the medium-high density conifer should be noted. The majority of the low density commission errors were made by categorizing this resource type as either medium-high density conifer or as brush-dry site hardwood. It is probable that many of these errors were subjective. There are few situations where the transition from medium to low density conifers is abrupt; therefore the categorization of stocking levels requires a greater value judgment on the part of the interpreter. Moreover, most low density conifer stands have dense understories of brush and hardwoods. Hence the interpreter is required to make another difficult value judgment as to whether to categorize an area as low density conifer with brush understory or to categorize it as a brush field with interspersed conifers.

Note that for the percent commission error for the medium-high density conifer type, statistically significant differences occurred in which IR-301+25, Enhancement 1 and Enhancement 2 contained more information than IR-89B and Enhancement 3. Interestingly, the two poorest image types, IR-89B and Enhancement 3, had commission errors of different types. The IR-89B commission errors were due mostly to categorizing medium-high density conifer as low density conifer, while the Enhancement 3 commission errors were due to categorizing it as brush-dry site hardwood. This kind of inconsistency is most likely attributable to variation in interpreter performance.

(2) Brush-Dry Site Hardwoods. With the exception of Enhancement 3, all image types provided an acceptable accuracy level for the identification of brush-dry site hardwoods. Enhancement 3 was shown statistically to be the poorest image type for categorizing this resource type for both percent correct and percent commission error. While the separation of nonvegetative types (i.e., pink areas) on Enhancement 3 from vegetative types (i.e., green areas) is very distinct, the separation within vegetative types, particularly those of the same texture, is particularly confusing. Coniferous types are easily identified by their form, but the separation of the smooth textured brush fields and meadows must be done using varying shades of green only. The test results show that this variation is neither distinct nor consistent enough to give accurate categorization of these resource types and that the enhancement somehow obscures information that may have been present on the separate IR-301+25 and IR-89B imagery that was used in part to form the enhancement.

(3) Meadow-Riparian Hardwoods. For the most part, the same comments concerning the preceding resource type apply here, i.e., the inability of Enhancement 3 to distinguish between meadows and brushfields. However, in the case of the meadow-riparian hardwood type, the test results showed no significant differences between image types, and Enhancement 3 was poorest in

absolute rankings of percent correct and percent commission error only. However, there appears to be a trend of lower commission errors for this resource type than for the brush-dry site hardwood. This lower error could have been caused again by the high resolution of all the imagery. Thus, the skilled interpreter could easily identify the riparian hardwoods by their characteristic meander pattern and not have to depend upon their tonal characteristics alone.

(4) Rock - Bare Soil. IR-89B was shown statistically to be poorer than the other image types for categorizing this resource type. The three enhancements and IR-301+25 ranged from 90 to 100 percent correct identification while the IR-89B averaged only 64 percent correct identification. All commission errors for rock - bare soil for IR-89B were the result of the resource being mistakenly categorized as resources with similar smooth textures such as brush or meadow.

(5) Water. This is the one resource type that was identified 100 percent correctly. In one case, however, an interpreter using Enhancement 3 made a commission error by categorizing some standing water, as water.

Two summary remarks concerning the mapping and categorizing of forest types using single and multiband imagery of this resolution can be made: (1) for resource types with distinctive shapes (conifers) or growth patterns (riparian hardwoods), different film or enhancement types will give virtually the same accuracy of identification, and (2) for resource types with less distinctive texture or growth patterns, carefully selected image types will aid in proper identification. Three resource types that fall into this latter category are brush - dry site hardwood, meadow, and rock - bare soil. Of the five image types tested, IR-89B and Enhancement 3 were significantly poorer for separating several of the resource types.

44.	7 GARLIC	6 TOMATO	5 POTATO	4 MILO	3 SAFFLOWER	2 WHEAT	1 BARLEY
BEANS	8 CUCUMBERS	9 BEANS	10 ONION	11 BEANS	12 SUGAR BEETS	13 MILO	14 SAFFLOWER
43A. ALFALFA	21 COTTON	20 MILO	19 PEPPER	18 POTATO	17 LETTUCE	16 COTTON	15 WHEAT
43B. ALFALFA	22 ONION	23 GARLIC	24 SUGAR BEETS	25 TOMATO	26 BARLEY	27 TOMATO	28 BARLEY
43C. ALFALFA	35 BEANS	34 CUCUMBERS	33 LETTUCE	32 POTATO	31 PEPPER	30 WHEAT	29 SAFFLOWER
	36 GARLIC	37 ONION	38 PEPPER	39 CUCUMBERS	40 LETTUCE	41 SUGAR BEETS	42 COTTON

Figure 15. Crop array planted adjacent to a 150-foot water tower at the Davis test site.

accuracy of crop identification and showed no statistical differences between image types.

The crop array, however, was an ideal target for testing information content on multiband (and multidate) imagery using a densitometer to measure image optical densities. Specifically, imagery obtained throughout the growing season from the water tower was measured in terms of the percent transmission through the negative image to determine which of the film/filter combinations tested provided the greatest discrimination between crops. The experiment and its results are described below (Roberts and Gialdini, 1970).

The following 15 crops, with the exception of alfalfa, were planted in 12' by 12' plots located in a random fashion within a six by seven array: alfalfa, tomato, potato, milo, safflower, wheat, barley, cucumber, beans, onion, sugar beets, cotton, lettuce, and garlic. The crops were planted denser than usual in order to quickly form a complete vegetative canopy. The purpose of this experiment was to evaluate tone differences on the photos resulting from differences in the radiation reflected from the soil through varying degrees of canopy closure. For this reason crops that did not form continuous cover were eliminated from further testing. The crops eliminated for this reason were garlic, cucumber, beans, onion, pepper, and lettuce.

The crops were photographed from atop the tower at weekly intervals. All photographs were taken from the same camera station with a Graphlex XL camera and Zeiss 80mm Planar lens at near midday. Two types of 70mm B/W film were used for the multispectral photography: Kodak Plus-X Aerographic, type 2401, a panchromatic aerial film sensitive from 400 nm to 710 nm; and Kodak Infrared Aerographic, type 2424, an aerial film sensitive from 400 nm to 900 nm in the near infrared. Approximate effective spectral bandwidths of the film/filter combinations used are listed in Table 8.

TABLE 8. SPECTRAL BANDWIDTHS OF THE FILM/FILTER COMBINATIONS USED DURING
THE DAVIS WATER TOWER EXPERIMENT.

PLUS-X AEROGRAPHIC		INFRARED AEROGRAPHIC	
FILTER	EFFECTIVE SPECTRAL BANDWIDTH	FILTER	EFFECTIVE SPECTRAL BANDWIDTH
2A	410-710 nm	89B	700-900 nm
8	470-710 nm	87C	810-900 nm
12	510-710 nm	25	590-900 nm
21	550-710 nm	87B	890-900 nm
25	590-710 nm	88A	740-900 nm
30	400-470 and 570-710 nm	301[1]	400-700 nm
47B	400-470 nm	301 + 47B	400-470 nm
58	500-580 nm	301 + 58	500-580 nm
70	600-710 nm	301 + 70	660-700 nm
102	480-790 nm	301 + 21	550-700 nm
73	560-590 nm	301 + 75	470-520 nm
75	470-520 nm	301 + 99	530-570 nm
99	530-570 nm	301 + 73	560-590 nm
70 + 301	660-700 nm		

[1]The 301 is an infrared blocking interference filter that cuts off radiation
longer than about 700 nm.

(From Roberts and Gialdini, 1970.)

The negative density was measured for each field on each film/filter combination for photography taken on August 14, 1969. A selected group of film/filter combinations were measured on the other dates. Measurements were made by Welsh Densicron using a 1 mm aperture. This aperture size reduced the variance by integrating a representative field area. The percent transmission for a field is an average of three measurements randomly located within the field. Measurements were periodically spot-checked by a second operator to ensure high precision.

Test Results. Table 9 shows results for Plus X film taken on July 31, 1969 with a Wratten 25 filter. The lines to the left of the crop names denote homogeneous density groupings. There is no significant difference between the image densities for crops preceded by the same line. For the image of crops not preceded by the same line there exists a significant difference at the 95 percent protection level.

Discussion of Results. Table 9 may be interpreted as follows: barley and wheat are preceded by the same line and therefore are not significantly different from one another in the rankings. They are, as a subset, different from all the other crops listed. Sugar beets and alfalfa form a homogeneous sub-set with sugar beets being significantly different from all other crops. Alfalfa is, in addition, a member of a homogeneous sub-set including milo, cotton, and tomato. Alfalfa is significantly different from barley, wheat, potato and safflower. Milo, cotton, and tomato are, in turn, included in a subset with potato. Potato and safflower form a sub-set with safflower being significantly different from all the other crops.

Table 10 presents the same data in a different form and lists each crop, the crops from which it is not significantly different, and the crops from which it is significantly different. This table may initially be some-

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TABLE 9. ANALYSIS OF DIFFERENT CROP FILM DENSITIES FOR PLUS X FILM
EXPOSED THROUGH A WRATTEN 25 FILTER.

Analysis of Variance

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
Between groups	.2459	8	.0307	35.9266
Within groups	.0154	18	.0009	
Total	.2613	26		

Treatment Means in Ranked Order

LABEL	MEAN	STANDARD DEVIATION
Barley	.07367	.0505
Wheat	.07900	.0631
Sugar Beets	.21067	.0706
Alfalfa	.25133	.0379
Milo	.27667	.0631
Cotton	.27767	.0521
Tomato	.29800	.0527
Potato	.32200	.0486
Safflower	.36067	.0496

(From Roberts and Gialdini, 1970.)

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TABLE 10. ALTERNATE PRESENTATION OF DATA SHOWN IN TABLE 8 FOR PLUS X/
           WRATTEN 25 PHOTOGRAPHY OBTAINED ON JULY 31, 1969.

CROP TYPE	NOT SIGNIFICANTLY DIFFERENT FROM	SIGNIFICANTLY DIFFERENT FROM
Barley	Wheat	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Wheat	Barley	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Sugar beets	Alfalfa	Barley, wheat, milo, cotton, tomato, potato, safflower
Alfalfa	Sugar beets, milo, cotton, tomato	Barley, wheat, potato, safflower
Milo	Alfalfa, cotton, tomato, potato	Barley, wheat, sugar beets, safflower
Cotton	Alfalfa, milo, tomato, potato	Barley, wheat, sugar beets, safflower
Tomato	Milo, cotton, potato, alfalfa	Barley, wheat, sugar beets, safflower
Potato	Milo, cotton, tomato, safflower	Barley, wheat, sugar beets, alfalfa
Safflower	Potato	Barley, wheat, sugar beets, alfalfa, milo, cotton, tomato

(From Roberts and Gialdini, 1970.)

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what easier to understand for a person not familiar with Duncan's new multiple range test; however, the technique of joining with lines ranked data which is not significantly different does provide a condensed, yet unambiguous, presentation.

A survey of the results from Duncan's new multiple range test suggests that for this particular target array and date no single film/filter combination can be used to discriminate among all crops. By using two or more film/filter combinations in concert, however, a greater number of discriminations can be made. For example, by the addition of data from the Plus X/Wratten 47B combination (Table 11) to the data from the Plus X/Wratten 25 combination, which we have been examining, the following additional crop discriminations can be made: sugar beets from alfalfa, alfalfa from cotton, cotton from tomato, cotton from potato. These results are shown in Table 12 and can be compared with Table 10.

A further gain in the ability to discriminate between crops can be made by utilizing multidate photography. For example, by examining in concert data from two dates for one of the film/filter combinations (Plus X/Wratten 25), Table 13 can be constructed. In this example, the data from the first and last weeks of the series of photographs measured provided the greatest amount of information. Utilizing data from the intervening dates provides no additional information within this spectral band. Thus, just as particular spectral bands when used in concert for one date will give the best discrimination between crops for that date, particular dates when used in concert for one band will also improve the ability to discriminate between crop types. It follows that there should be a particular combination of spectral bands and dates that will give better results than either alone. The following combination of film/ filter/dates, although probably not unique, gives complete statistical discrim-

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TABLE 11. ANALYSIS OF DIFFERENT CROP FILM DENSITIES FOR PLUS X FILM EXPOSED
THROUGH A WRATTEN 47B FILTER.

Analysis of Variance

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
Between groups	.1681	8	.0210	18.9019
Within groups	.0200	18	.0011	
Total	.1882	26		

Treatment Means in Ranked Order

LABEL	MEAN	STANDARD DEVIATION
Barley	.27767	.0329
Wheat	.31900	.0735
Sugar beets	.38267	.0895
Cotton	.42400	.0446
Milo	.45800	.0720
Tomato	.48200	.0666
Safflower	.49767	.0302
Alfalfa	.49767	.0172
Potato	.50533	.0249

(From Roberts and Gialdini, 1970.)

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TABLE 12.   DATA FROM TABLES 9 AND 11 USED IN COMBINATION ALLOWING
ADDITIONAL CROP DISCRIMINATIONS TO BE MADE.

CROP TYPE	NOT SIGNIFICANTLY DIFFERENT FROM	SIGNIFICANTLY DIFFERENT FROM
Barley	Wheat	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Wheat	Barley	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Sugar beets		Barley, wheat, milo, cotton, tomato, potato, safflower, alfalfa
Alfalfa	Milo, tomato	Barley, wheat, potato, safflower, sugar beets, cotton
Milo	Alfalfa, cotton, tomato, potato	Barley, wheat, sugar beets, safflower
Cotton	Milo	Barley, wheat, sugar beets, safflower, alfalfa, tomato, potato
Tomato	Milo, potato, alfalfa	Barley, wheat, sugar beets, safflower, cotton
Potato	Milo, tomato, safflower	Barley, wheat, sugar beets, alfalfa, cotton
Safflower	Potato	Barley, wheat, sugar beets, alfalfa, milo, cotton, tomato

(From Roberts and Gialdini, 1970.)

TABLE 13. IMPROVEMENT IN DISCRIMINATION RESULTING FROM USE OF DATA
          FROM ONE FILM/FILTER COMBINATION (PLUS X/WRATTEN 25) AND
          TWO DATES (JULY 17 AND AUGUST 14).

CROP TYPE	NOT SIGNIFICANTLY DIFFERENT FROM	SIGNIFICANTLY DIFFERENT FROM
Barley	Wheat	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Wheat	Barley	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Sugar beets		Barley, wheat, alfalfa, milo, cotton, tomato, potato, safflower
Alfalfa		Barley, wheat, sugar beets, milo, cotton, tomato, safflower
Milo	Potato	Barley, wheat, sugar beets, alfalfa, cotton, tomato, safflower
Cotton		Barley, wheat, sugar beets, alfalfa, milo, cotton, potato, safflower
Tomato		Barley, wheat, sugar beets, alfalfa, milo, cotton, potato, safflower
Potato	Milo	Barley, wheat, sugar beets, alfalfa, cotton, tomato, safflower
Safflower		Barley, wheat, sugar beets, alfalfa, milo, cotton, tomato, potato

(From Roberts and Gialdini, 1970.)

ination among the crops tested: Plus X/Wratten 25 on July 17 and August 14, and IR-301+58 on July 25.

Imperial Valley Test Site

Test Setup. A complementary experiment concerning agricultural resources was conducted in the Imperial Valley, California. Cropping in the Imperial Valley is mainly on reclaimed desert land, where the combination of deep rich soils, an abundance of solar energy and available irrigation water has led to a level of agricultural productivity equaled in only a few parts of the world.

Aircraft flights were arranged for this area during the summer of 1969 for the purpose of obtaining high quality single-band, B/W multiband and tri-emulsion color and false-color photographs. All photography was procured by the Science and Engineering Group at LIU. Our objective was to determine the usefulness of different kinds of multiband photography (flown in July) for identifying four Imperial Valley cropland categories: alfalfa, sorghum, cotton and bare soil.

Five sets of images were selected for testing--one set of single-band photos (IR-301+25) and four sets of multiband photos (Aerial Ektachrome, Ekta Aero Infrared, Enhancement A and Enhancement B). Enhancement A, a close simulation of Ekta Aero Infrared photography, was made by optically combining IR-301+58, IR-301+25 and IR-89B images projected through blue, green and red filters, respectively; while Enhancement B was made in a similar fashion but with the green and red filters reversed (see Figures 16 through 20).

Each set of imagery was examined by three interpreters with no inter-preter viewing more than one set. A set of images consisted of nine separate photos, in print form, mosaiced together containing a total of 157 agricutural fields (see Figure 21). Several fields were randomly selected within each crop category and were used as training samples by the photo interpreter.

Figure 16. IR-301+25 imagery and test results for the Imperial Valley, California, study area.

A: alfalfa
S: sorghum
C: cotton
BS: bare soil

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	34	3	3	5	45	11
S	11	14	3	1	29	15
C	8	1	4	1	14	10
BS	4	1		38	43	5
TOTAL FIELDS	57	19	10	45	131	41
OMIS. ERROR	23	5	6	7		

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	34	4	4	6	48	14
S	3	13			16	3
C	17	1	5	1	24	19
BS	3	2	2	36	43	7
TOTAL FIELDS	57	20	11	43	131	43
OMIS. ERROR	23	7	6	7		

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	41	10	5	3	59	18
S	6	4			10	6
C	4	6	5		15	10
BS	5	1	1	42	49	7
TOTAL FIELDS	56	21	11	45	133	41
OMIS. ERROR	15	17	6	3		

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Figure 17. Aerial Ektachrome imagery and test results for the Imperial Valley, California, study area.

A: alfalfa
S: sorghum
C: cotton
BS: bare soil

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	42	4	4		50	8
S	3	12		2	17	5
C	8	4	6		18	12
BS	2		1	41	44	3
TOTAL FIELDS	55	20	11	43	129	
OMIS. ERROR	13	8	5	2		28

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	42	6	1	9	58	16
S	13	13	2		28	15
C		2	7		9	2
BS	1		1	35	37	2
TOTAL FIELDS	56	21	11	44	132	
OMIS. ERROR	14	8	4	9		35

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	38	7	6	6	57	19
S	4	11	1	6	22	11
C	4		3		7	4
BS	10		1	33	44	11
TOTAL FIELDS	56	18	11	45	130	
OMIS. ERROR	18	7	8	12		45

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Figure 18. Ekta Aero IR imagery and test results for the Imperial Valley, California, study area.

A: alfalfa
S: sorghum
C: cotton
BS: bare soil

IMPERIAL VALLEY

INTERPRETER #1

INTERPRETER RESULTS	GROUND DATA A	S	C	BS	TOTAL SAMPLE	COM. ERROR
A	49	6	3	6	64	15
S	4	11			15	4
C		4	6		10	4
BS	1		1	39	41	2
TOTAL FIELDS	54	21	10	45	130	
OMIS. ERROR	5	10	4	6		25

INTERPRETER #2

INTERPRETER RESULTS	GROUND DATA A	S	C	BS	TOTAL SAMPLE	COM. ERROR
A	44	6	2		52	8
S	5	10			15	5
C	1	5	8		14	6
BS	6		1	45	52	7
TOTAL FIELDS	56	21	11	45	133	
OMIS. ERROR	12	11	3	0		26

INTERPRETER #3

INTERPRETER RESULTS	GROUND DATA A	S	C	BS	TOTAL SAMPLE	COM. ERROR
A	37	8	2	2	49	12
S	6	7			13	6
C	5	3	8		16	8
BS	4		1	43	48	5
TOTAL FIELDS	52	18	11	45	126	
OMIS. ERROR	15	11	3	2		31

Figure 19. Enhancement A imagery and test results for the Imperial Valley, California, study area.

A: alfalfa
S: sorghum
C: cotton
BS: bare soil

INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	34	12	2	5	53	19
S	8	5			13	8
C	11	3	8		22	14
BS	3		1	38	42	4
TOTAL FIELDS	56	20	11	43	130	
OMIS. ERROR	22	15	3	5		45

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	41	6	4	3	54	13
S	3	14	2		19	5
C	10	1	4		15	11
BS	2		1	42	45	3
TOTAL FIELDS	56	21	11	45	133	
OMIS. ERROR	15	7	7	3		32

INTERPRETER # 3

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	45	17	6	1	69	24
S	5	3	1		9	6
C	1	1	3		5	2
BS	4		1	44	49	5
TOTAL FIELDS	55	21	11	45	132	
OMIS. ERROR	10	18	8	1		37

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Figure 20. Enhancement B imagery and test results for the Imperial Valley, California, study area.

A: alfalfa
S: sorghum
C: cotton
BS: bare soil

INTERPRETER #1

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	51	10	5	8	74	23
S	3	9			12	3
C	2	2	6		10	4
BS	1			35	36	1
TOTAL FIELDS	57	21	11	43	132	
OMIS. ERROR	6	12	5	8		31

INTERPRETER #2

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	50	5	3	11	69	19
S	3	14	2		19	5
C	1	1	5	1	8	3
BS	2			34	37	3
TOTAL FIELDS	56	20	11	46	133	
OMIS. ERROR	6	6	6	12		30

INTERPRETER #3

INTERPRETER RESULTS	GROUND DATA				TOTAL SAMPLE	COM. ERROR
	A	S	C	BS		
A	43	4	5	1	53	10
S	3	15			18	3
C	4	2	5		11	6
BS	5		1	43	49	6
TOTAL FIELDS	55	21	11	44	131	
OMIS. ERROR	12	6	6	1		25

Test Results. The photo interpretation results were summarized and statis-
tically analyzed (i.e., ANOVA and Duncan's new multiple range test). The
results of the statistical analyses are presented in Table 14. The ANOVA
indicated that interpretation results from various image types were statistically
different in only two cases, "all cropland, percent correct," and "cotton,
percent commission error." Further groupings for these two categories were
made using Duncan's new multiple range test, providing the information presented
in Table 15.

What is most evident in these results is that accuracy of identification
for all crop categories combined or taken singularly is relatively low (<80
percent), regardless of the type of test imagery used.

Discussion of Results. It is our opinion that these results are a
function of acquiring the imagery at a non-optimum time of the year for crop
identification, rather than the lack of information content in multiband photog-
raphy per se. An analysis of a crop calendar for this region illustrates this
point. Both cotton and sorghum are in a mature, green state of development in
July--a condition rendering tone signatures for the two crops quite similar
in appearance on single-band and multiband photographs. The low percent cor-
rect identifications and high percent commission errors for cotton and sorghum
indicate that the interpreter continually confused the two. Furthermore, the
alfalfa fields were in varying stages of development ranging from recently
cut to mature at this time of year, which added to the difficulty of identifying
one crop type from another. Nevertheless, some very definite trends are evident
in the data derived in these tests: (1) in all tests, the highest interpretation
accuracy for each crop category, including the combined category called "all
cropland," was obtained with either Enhancement B or Ekta Aero Infrared imagery.
For example, in terms of percent correct, three crop categories were best
interpreted on Enhancement B--all cropland (78 percent), alfalfa (86 percent)

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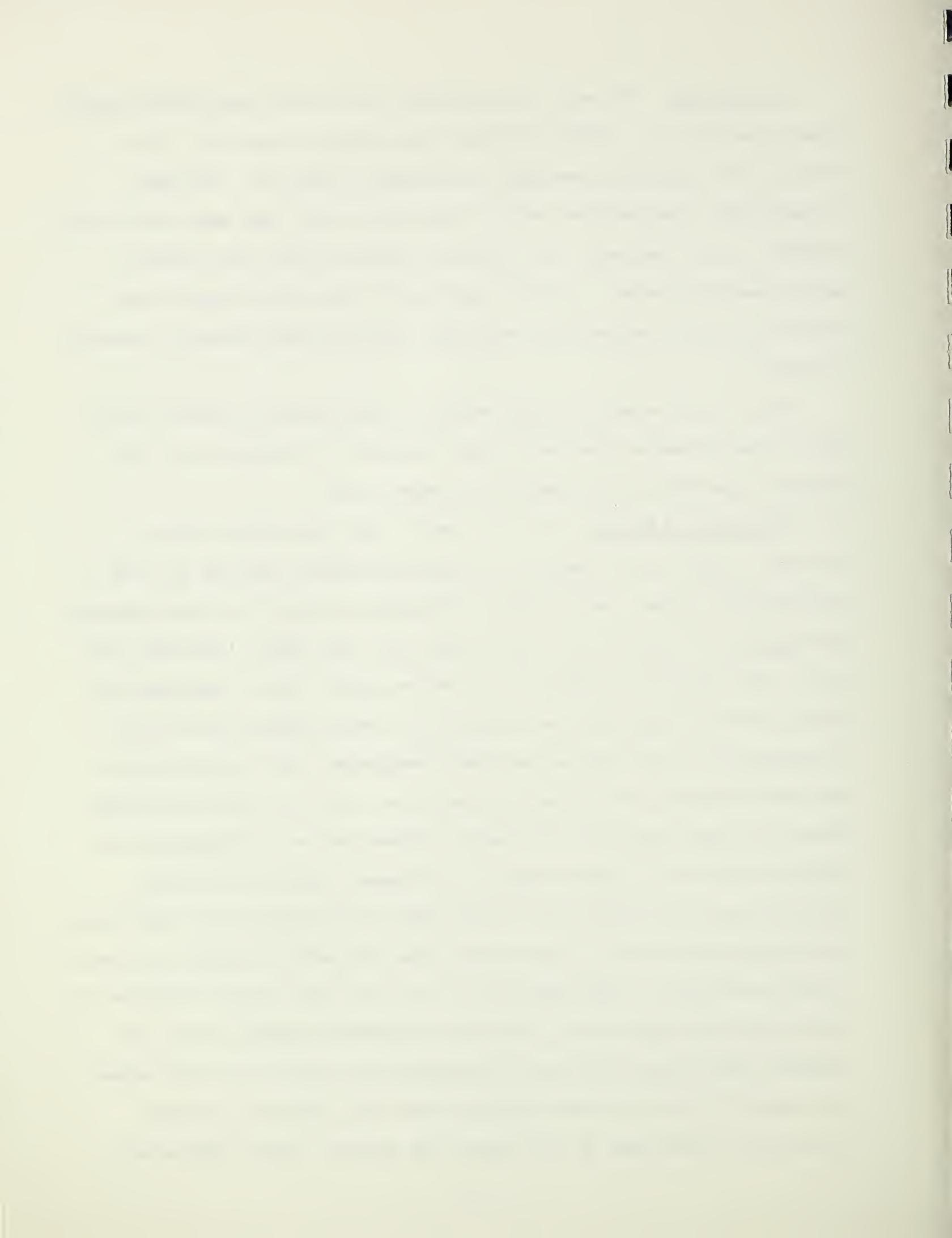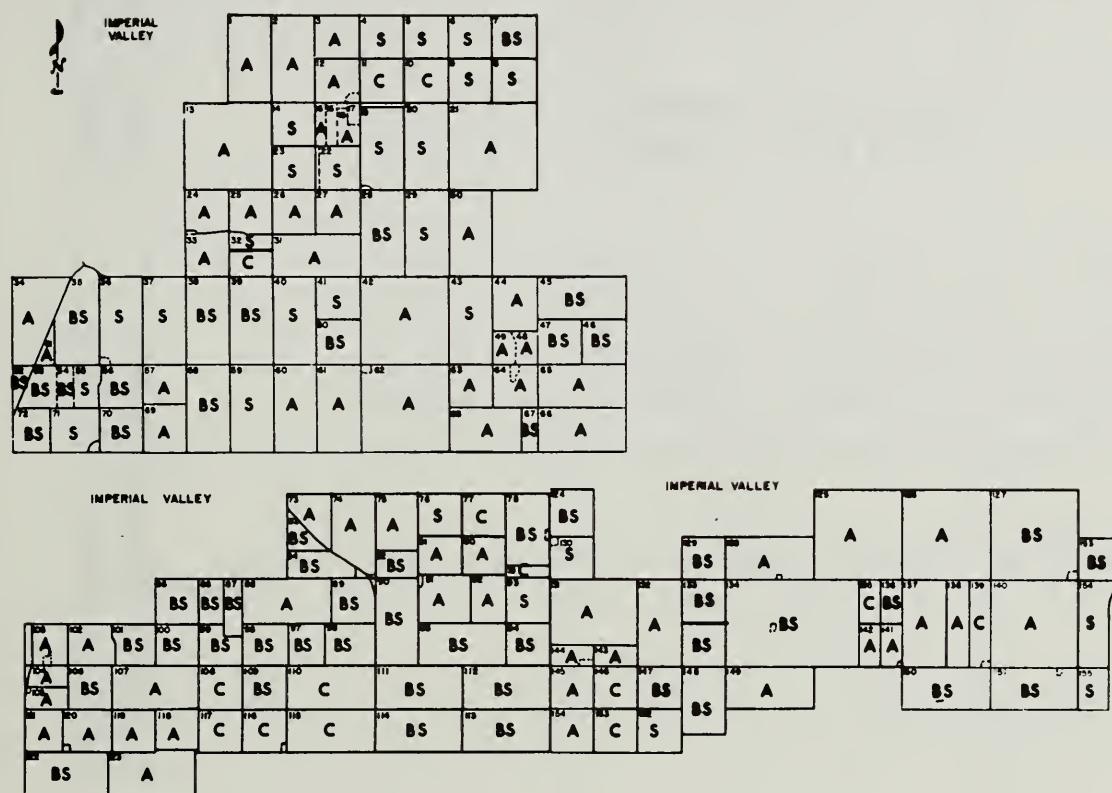
Figure 21. A ground truth map for the Imperial Valley, California, study
area. Fields are numbered in the upper left corner and the
symbols in the center of each field signify "A" for alfalfa,
"C" for cotton, "S" for sorghum, and "BS" for bare soil.
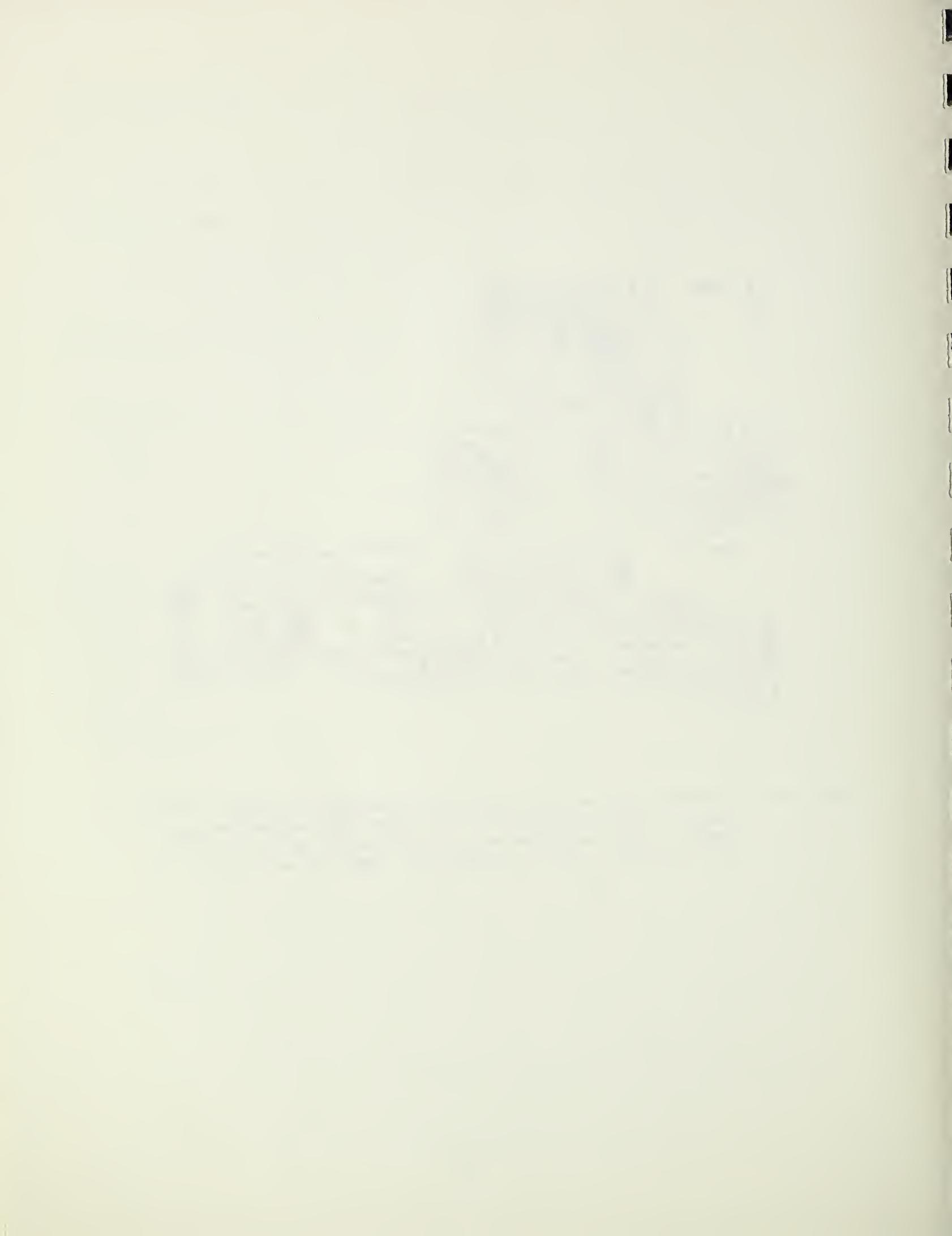
TABLE 14. IMPERIAL VALLEY, CALIFORNIA, IMAGE TYPES RANKED IN ORDER BY MEAN PERCENT CORRECT AND MEAN PERCENT COMMISSION ERROR FOR AGRICULTURAL CROP IDENTIFICATION.

CROP TYPE	RANKED IMAGES	PERCENT CORRECT	SIG. DIF.(0.1)	HOMO. GROUP(S)	RANKED IMAGES	% COMM. ERROR	SIG. DIF.(0.1)	HOMO. GROUP(S)
All Cropland	Enh B	78.4						
	Ek Aero IR	77.2						
	Aerial Ek	72.4	Yes					
	Enh A	71.2						
	IR-25	67.2						
Sorghum	Enh B	60.3			Enh B	22.7		
	Aerial Ek	60.3			Ek Aero IR	35.4	No	
	IR-25	47.6	No		IR-25	38.3		
	Ek Aero IR	44.4			Aerial Ek	43.1		
	Enh A	34.9			Enh A	51.5		
Alfalfa	Enh B	85.8			Ek Aero IR	21.6		
	Ek Aero IR	77.4			Aerial Ek	24.7	No	
	Aerial Ek	74.4	No		Enh B	25.3		
	Enh A	72.6			IR-25	29.8		
	IR-25	60.1			Enh A	31.6		
Cotton	Ek Aero IR	69.7			Enh B	39.5		
	IR-25	54.4			Ek Aero IR	44.9		
	Enh B	51.5	No		Aerial Ek	45.5	Yes	
	Aerial Ek	48.5			Enh A	59.0		
	Enh A	45.5			IR-25	73.6		
Bare Soil	Ek Aero IR	94.1			Enh B	7.6		
	Enh A	92.6			Enh A	7.9		
	IR-25	87.4	No		Ek Aero IR	9.6	No	
	Enh B	84.5			Aerial Ek	11.0		
	Aerial EK	82.2			IR-25	17.5		

TABLE 15. HOMOGENEOUS SUBGROUPS (DUNCAN'S NEW MULTIPLE RANGE TEST)
INDICATING SIGNIFICANTLY DIFFERENT IMAGE TYPES; IMPERIAL VALLEY,
CALIFORNIA.

TEST	IMAGE TYPE	SIGNIFICANTLY DIFFERENT FROM	NOT SIGNIFICANTLY DIFFERENT FROM
All cropland (% correct identifi- cation)	Enh B	Enh A and IR-25	Ek Aero IR and Aerial Ek
	Ek Aero IR	Enh A and IR-25	Enh B and Aerial Ek
	Aerial Ek		Enh B, Ek Aero IR, Enh A, IR-25
	Enh A	Enh B and Ek Aero IR	Aerial Ek and IR-25
	IR-25	Enh B and Ek Aero IR	Aerial Ek and Enh A
Cotton (% commission error)	Enh B	IR-25	Ek Aero IR, Aerial Ek, and Enh A
	Ek Aero IR	IR-25	Enh B, Aerial Ek, Enh A
	Aerial Ek	IR-25	Enh B, Ek Aero IR, Enh A
	Enh A		Enh B, Ek Aero IR, Aerial Ek, IR-25
	IR-25	Enh B, Ek Aero IR, Aerial Ek	Enh A

72
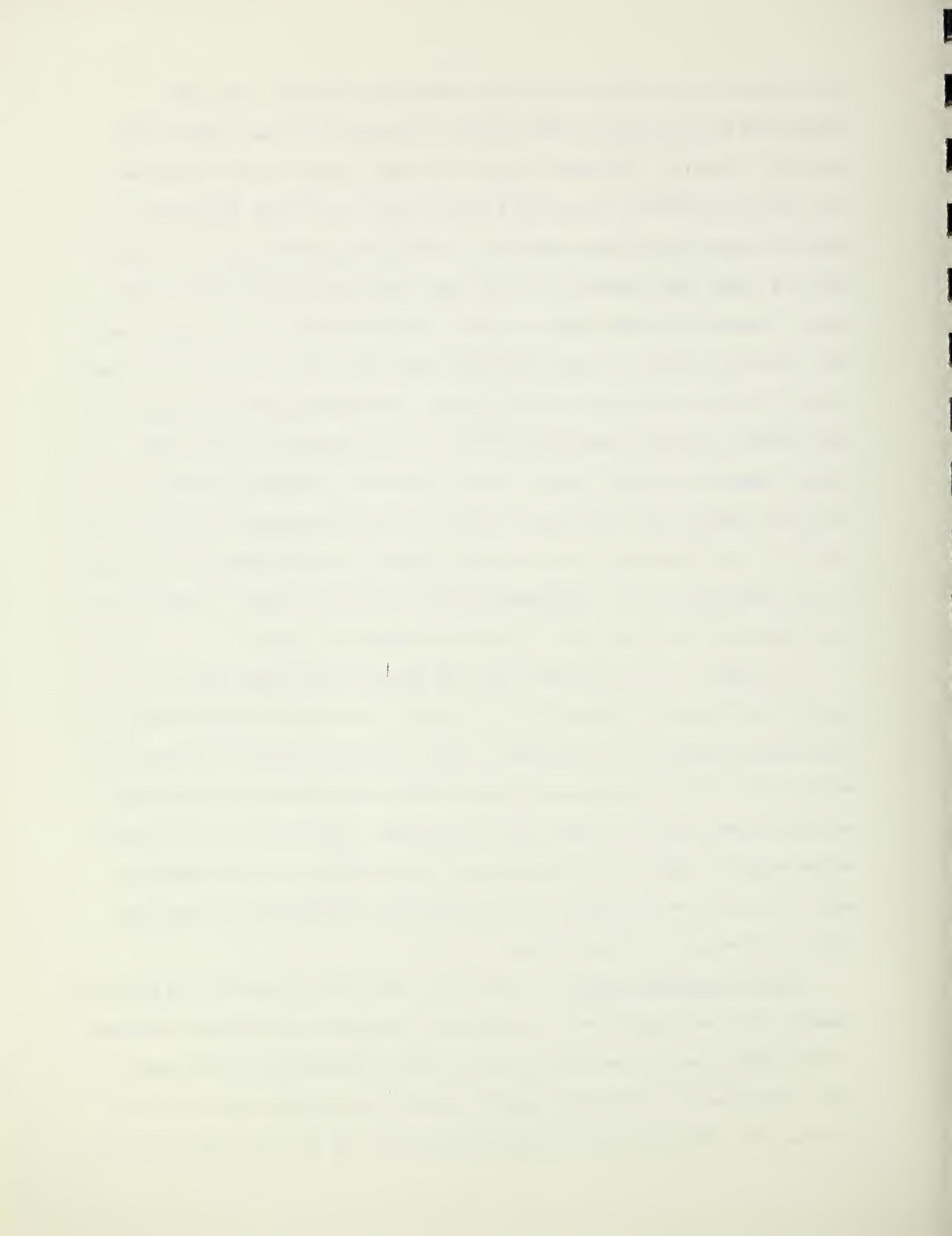
RANDOMLY SELECTED GROUP

INTERPRETER # 1

		GROUND DATA				TOTAL SAMPLE	COM. ERROR
		A	S	C	BS		
INTERPRETER RESULTS	A	34	3	3	5	45	11
	S	11	14	3	1	29	15
	C	8	1	4	1	14	10
	BS	4	1		38	43	5
TOTAL FIELDS		57	19	10	45	131	
OMIS. ERROR		23	5	6	7		41

INTERPRETER # 2

		GROUND DATA				TOTAL SAMPLE	COM. ERROR
		A	S	C	BS		
INTERPRETER RESULTS	A	34	4	4	6	48	14
	S	3	13			16	3
	C	17	1	5	1	24	19
	BS	3	2	2	36	43	7
TOTAL FIELDS		57	20	11	43	131	
OMIS. ERROR		23	7	6	7		43

INTERPRETER # 3

		GROUND DATA				TOTAL SAMPLE	COM. ERROR
		A	S	C	BS		
INTERPRETER RESULTS	A	41	10	5	3	59	18
	S	6	4			10	6
	C	4	6	5		15	10
	BS	5	1	1	42	49	7
TOTAL FIELDS		56	21	11	45	133	
OMIS. ERROR		15	17	6	3		41

SKILLED GROUP

INTERPRETER # 4

		GROUND DATA				TOTAL SAMPLE	COM. ERROR
		A	S	C	BS		
INTERPRETER RESULTS	A	44	8	2	2	56	12
	S	8	8	2	1	19	11
	C		3	7	1	11	4
	BS	2	1	1	42	46	4
TOTAL FIELDS		54	20	12	46	132	
OMIS. ERROR		10	12	5	4		31

INTERPRETER # 5

		GROUND DATA				TOTAL SAMPLE	COM. ERROR
		A	S	C	BS		
INTERPRETER RESULTS	A	47	6	1	11	65	18
	S	1	7			8	1
	C	3	5	8	1	17	9
	BS	7	3	1	38	49	11
TOTAL FIELDS		58	21	10	50	139	
OMIS. ERROR		11	14	2	12		39

INTERPRETER # 6

		GROUND DATA				TOTAL SAMPLE	COM. ERROR
		A	S	C	BS		
INTERPRETER RESULTS	A	41	12	2	4	59	18
	S	10	7	2		19	12
	C	1	2	6	1	10	4
	BS	4		1	40	45	5
TOTAL FIELDS		56	21	11	45	133	
OMIS. ERROR		15	14	5	5		39

SUMMARY OF INTERPRETATION RESULTS

INTERPRETER	RANDOM GROUP	SKILLED GROUP
1	67.7%	75.2%
2	69.2	75.9
3	64.7	70.7
Mean Percent Correct	67.2	73.9
Standard Deviation	2.3	2.8

Figure 22. Interpretation results obtained from IR-301+25 imagery using two groups of interpreters, one specifically selected on the basis of highest degree of training and skill and the other possessing varying degrees of training and experience.

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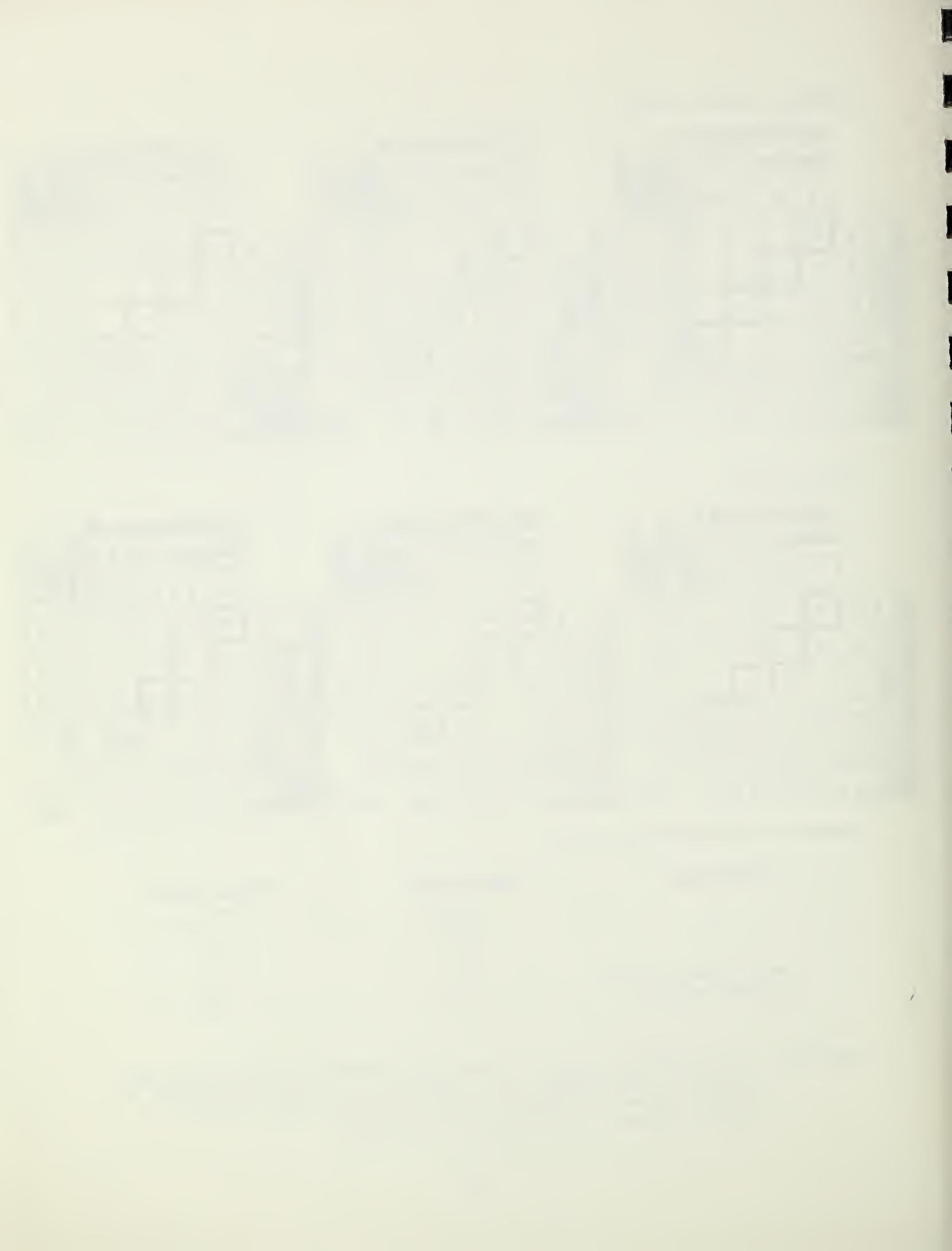
combined were used in the subsequent analysis. A statistical test (a one-sided "t" test) was carried out on these data for the purpose of determining if the highly skilled group could do a significantly better job of photo interpretation than could the other group. It was concluded that the highly skilled group utilized the IR-301+25 imagery better than did the randomly picked group.

The skilled group undoubtedly was able to apply the interpretation process known as "convergence of evidence" with a higher degree of proficiency. It appears that both groups interpreted crop category tone signatures equally well. The highly skilled group, however, was more proficient at recognizing subtle identifying characteristics such as harvesting cycles, irrigation methods, planting patterns, etc., each of which, when recognized, correctly identified and correlated with tone signature information, can lead to an even higher degree of crop identification accuracy than if identifications are made by studying tone signature alone.

Negative Density Measurements. A corollary study was conducted to determine the extent to which microdensitometry would support human interpretation results. Due to the present status of our data processing system configuration, only preliminary analyses could be performed in time for inclusion in this report. Nevertheless, some very interesting aspects were uncovered about possible man/machine interactions. The purpose of the following discussion is to describe the methods and results of our preliminary study using recorded optical density measurements as an additional complementary tool for multiband imagery interpretation.

The study consisted of (1) randomly selecting fields for each crop type and condition within the area of interest (bare fields were omitted since it subjectively appeared that these fields would not be difficult to discriminate from vegetated fields); (2) sampling and recording optical densities for each field selected; and (3) performing analysis of variance tests upon these data

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for the purpose of documenting species variability and condition variability. No attempt was made in this preliminary effort to apply classification routines as a means of comparing the manual interpretation results with automated techniques.

Digitization of film transparencies was conducted using equipment contained within the FRSL. This equipment consisted of a computer-controlled microdensitometer with paper tape or magnetic tape records serving as input data to the analysis of variance routines. The range of grey scale discrimination with our microdensitometer was over 1,000 discrete levels. Each field's optical density was measured from the transparencies employing a sampling procedure which yielded over 100 uniformly-spaced recordings per field. Only the B/W positive transparencies were measured during this initial digitization work (i.e., IR-301+25, IR-301+47B, IR-301+58, IR-89B).

In Table 16, measurements for the major crop types are listed. The data for the green band and the red band are listed for comparison. We have observed from prior studies that the optical density variability of field signatures is decidedly less using the green band than using the red band, since there is usually greater contrast between crop and soil background on the red band. Note in Table 16 that variability within fields exposed using the green band is less than that exhibited by the red band. Of course, for automatic classification routines to be effective, variation of density signatures within both fields and crop types must be minimal when compared to variation of density signatures between fields and crop types.

The overall result of our statistical analyses of these optical density data perhaps supports the interpreters' poor results. Each field exhibited a "unique" signature such that no commonality of crop density could be defined. The percent background versus vegetation in these examples was found to be
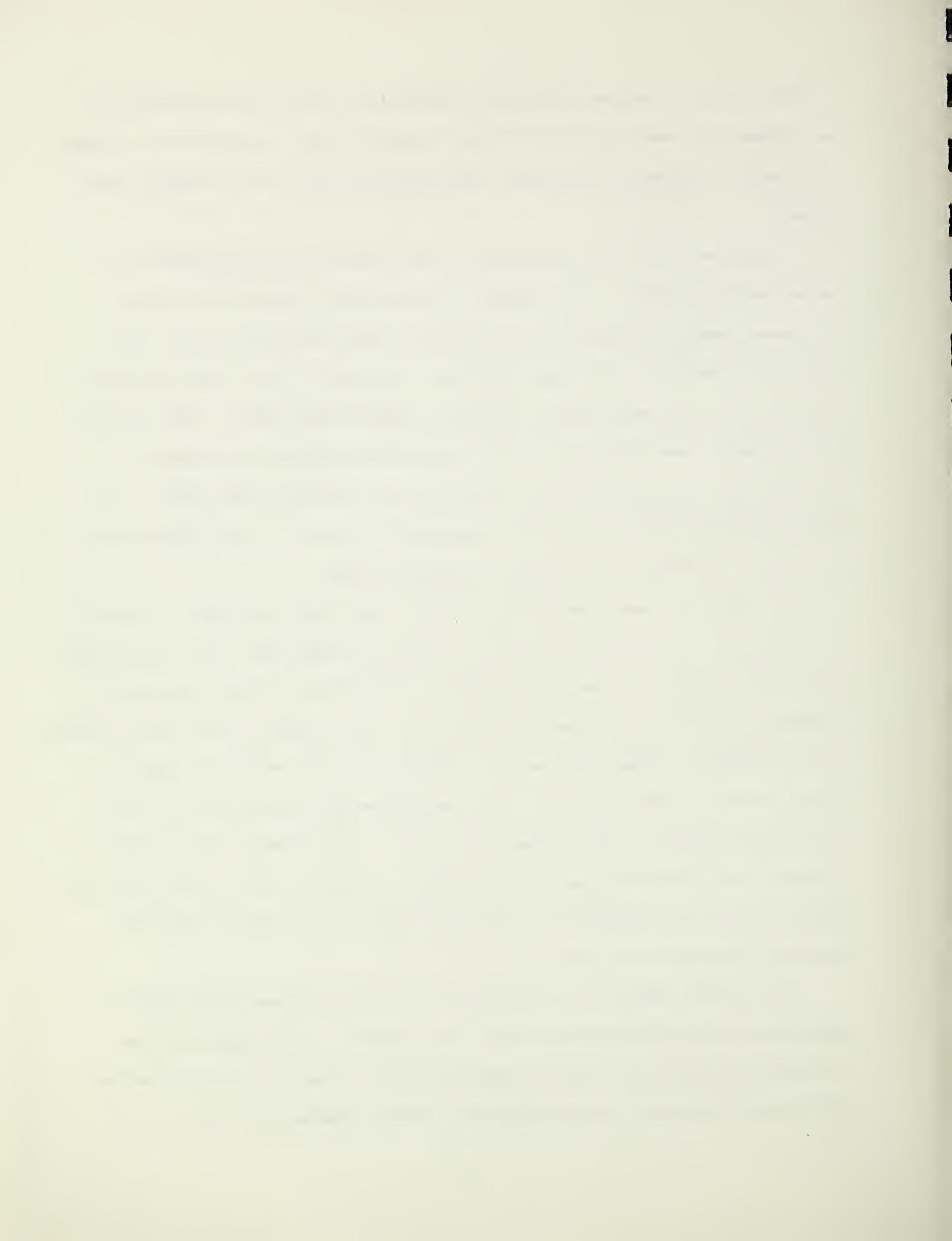
TABLE 16. SUMMARY OF OPTICAL DENSITY MEASUREMENTS, IMPERIAL VALLEY TEST SITE.

The following table lists the four major crops in the area. Crop conditions are noted as young, mature and cut. Both green and red band statistics are listed for comparison of variability of tone by field.

FIELD	TYPE	CONDITION	GREEN		RED	
			MEAN	ST. DEV.	MEAN	ST. DEV.
14	Sorghum	Cut	1910	55.8	1462	26.9
36	Sorghum	Young	1557	50.1	1204	50.4
6	Sorghum	Mature	1917	77.7	1811	223.6
9	"	"	2033	40.8	1912	77.1
76	"	"	1979	42.0	1821	57.9
93	"	"	1905	31.8	1828	29.6
22	"	"	1547	17.9	1444	21.7
41	"	"	1206	51.1	1176	19.9
40	"	"	1574	78.3	1607	112.6
55	"	"	1558	80.9	1555	92.8
116	Cotton	Young	1516	21.6	1374	35.8
117	"	"	1729	36.9	1622	71.9
110	"	"	1480	77.8	1317	53.8
146	"	"	1391	46.1	1183	20.0
139	"	"	1844	49.9	1643	108.5
11	"	"	1962	13.3	1483	13.1
77	Cotton	Mature	1930	20.6	1714	49.1
44	Alfalfa	Young	1662	47.3	1473	95.7
62	"	"	1427	58.1	1082	46.4
30	"	"	1219	68.6	1063	71.0
12	"	"	1833	20.5	1372	12.8
1	Alfalfa	Cut	2653	48.1	2691	43.6
138	"	"	1991	37.4	1914	62.1
80	"	"	2068	40.1	1919	109.5
128	"	"	1636	60.4	1641	86.8
24	"	"	1480	30.6	1577	72.5
13	Alfalfa	Mature	1438	86.6	1510	105.4
27	"	"	1580	33.9	1158	33.1
120	"	"	1517	38.1	1308	49.8
107	"	"	1702	17.9	1638	186.6
88	"	"	1211	75.9	1238	156.8
25	Rye	Young	1361	29.0	1036	12.5
102	Rye	Cut	1691	39.5	1565	51.6
73	"	"	1968	43.2	2139	22.9
75	"	"	2125	19.5	2163	32.4

TABLE 16. (cont.) SUMMARY OF OPTICAL DENSITY MEASUREMENTS, IMPERIAL VALLEY TEST SITE.

The following table lists the four major crops in the area. Crop conditions are noted as young, mature and cut. Both green and red band statistics are listed for comparison of variability of tone by crop.

TYPE	CONDITION	NUMBER OF FIELDS SAMPLED	NUMBER OF SAMPLING POINTS/BAND	GREEN MEAN	GREEN ST. DEV.	RED MEAN	RED ST. DEV.
Sorghum	Cut	1	144	1910	55.8	1462	26.9
Sorghum	Young	1	432	1557	50.1	1204	50.4
Sorghum	Mature	8	1,584	1675	247.0	1629	225.0
Cotton	Young	6	1,440	1657	204.6	1454	571.5
Cotton	Mature	1	144	1930	20.6	1714	49.1
Alfalfa	Young	4	2,016	1428	168.4	1127	134.5
Alfalfa	Cut	5	1,390	2045	119.5	2025	147.1
Alfalfa	Mature	5	2,016	1462	110.3	1439	209.5
Rye	Young	1	144	1361	29.0	1036	12.5
Rye	Cut	3	576	1977	180.3	2007	258.6

highly variable in all crop types. Further processing using a more controlled set of images in terms of ground truth will undoubtedly improve the technique employed here. It is further desired that these data be examined from the standpoint of classification techniques using the FRSL data processing system.

Electronic Enhancements. A portion of the Imperial Valley study area imaged on the LIU B/W multiband photograph was electronically enhanced using the Image Discrimination, Enhancement, Combination and Sampling (IDECS) system at the Center of Research in Engineering Sciences (CRES), University of Kansas. This system, which is considerably more complex and more expensive to develop than the more common optical enhancement devices, produces enhanced images by means of slicing and electronically expanding very subtle grey level differences measured on two or more multiband B/W images (currently only two flying-spot scanners are operating in the IDECS system, thereby restricting its operation to only two channels). Also, by electronic means, different color codes can be assigned to specific input densities and color enhancements can be displayed on a television monitor. A trained analyst operating the IDECS selects the optimum level of tone or brightness range, i.e., isodensity slice, that best characterizes the resource feature of interest on one or more images, taken separately or combined, and makes an isodensity enhancement of the feature using the color code of his choice. The IDECS system is continually being modified; ultimately encoded spectral densities will be directly analyzed by on-line computer software.

An example of enhanced imagery made on the IDECS system is shown in Figure 23. Thirty-six fields within the Imperial Valley study area are shown color coded based on density slices made from IR-301+25 and IR-89 imagery (LIU imagery, flown in July 1969). An attempt was made by the operator to isolate a single density level (derived from the two images simultaneously) unique to

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LEGEND

CROP CATEGORY	COLOR CODE
Cotton (C)	Blue
Sorghum (S)	Green
Alfalfa (A)	Red
Bare Soil	
(BS)	White

CROP TYPE	FIELDS CORRECTLY COLOR CODED	FIELDS INCORRECTLY COLOR CODED	TOTAL FIELDS	PERCENT CORRECT
Cotton	3	0	3	100
Sorghum	10	4	14	71
Alfalfa	8	5	13	61
Bare Soil	6	0	6	100
All Cropland	27	9	36	75

Figure 23. Electronically enhanced multiband imagery of a portion of the Imperial Valley study area. The IDECS system at Kansas University was used to make this color composite. Note that in most cases each field was assigned a unique color; however, some fields were incorrectly coded, while others were given more than one color depending on tonal changes within a field (caused by salt conditions, harvesting patterns, etc.). See text for discussion.

each crop category. It was impossible to do this for all fields because of the extreme variability in negative density found <u>within</u> each crop category-- which was often greater than the variation in negative density <u>between</u> crop categories (see the preceding section for a discussion of this problem). Nevertheless, the operator was able to choose a density slice for each crop category that was most representative for the fields on the test image and assigned a brilliant color to each slice (i.e., cotton: blue; sorghum: green; alfalfa: red; and bare soil: white). The table in Figure 23 presents a summary of those fields correctly and incorrectly color coded. Note that only three-fourths of the fields were correctly color coded, which supports the conclusion that if discrete information is not contained within the multiband imagery in the form of meaningful negative density differences, even the most elaborate enhancement devices will not be capable of producing a highly interpretable image. Here, as was the case when human photo interpreters attempted to classify these same fields on the various types of multiband imagery, a high degree of correct field identification was not possible because the imagery was obtained on a single date in midsummer. Note, however, that an electronic system can enhance subtle grey tones and display them as colors much more brilliantly than the optical enhancement system (n.b., cotton and sorghum). Very encouraging results were derived for the Phoenix-Mesa area using the IDECS system, and these results are discussed later in this report; for that study, multiband/multidate imagery was used as input data.

Phoenix-Mesa Test Site

Test Set-up. We first became involved in crop studies at the Phoenix-Mesa Test Site (NASA Test Site #29) while preparing for the Apollo 9 S065 multispectral photographic experiment. A 16 square mile area was chosen for intensive analysis; the 125 fields within the study area included most of the

economically important crop types found in irrigated regions of the southwest. In addition to the Apollo 9 multiband photography, NASA made available high-altitude aircraft multiband/multidate photography for this area. These aircraft overflights occurred sequentially at approximately one-month intervals, beginning at the time of the Apollo 9 flight. Given available multiband and multidate photography, interpretation tests were devised to establish the best combination(s) of images for identifying all crop categories and single crop types within the 16 square mile area (see Figure 24).

Test Results. A large number of test images, 11 of which are illustrated in Figures 25 through 27, were presented to the group of photo interpreters. They were then asked to classify each of the 125 fields into one of seven crop categories that included barley (B), recently cut alfalfa (Ac), mature alfalfa (Am), wheat (W), sugar beets (SB), moist bare soil (BSm) and dry bare soil (BSd). The interpretation results, expressed in percent for all crops combined, have been summarized and are shown in Table 17.

Discussion of Results. The interpretability of Apollo 9 and high-flight photographs (Pan-25, IR-89B and Ekta Aero Infrared) were compared; and in each case, the interpreters were able to identify the various crop categories field by field equally well on spaceborne and airborne photos. Note that single-band photographs taken on single dates produced overall interpretations results of fairly low accuracy, except for the Pan-25 image taken in May. Improved results were obtained with May photos because barley had sufficiently matured (i.e., turned brown) at that time, enabling it to be easily discriminated from all other crops. Overall interpretation accuracies for all crops improved substantially when single-date photography, including the May photos, were viewed in a multiband form (i.e., Ekta Aero Infrared photo or optically combined color composite image) and when single-band photos

IMAGE #1 PAN-25A, APOLLO 9
MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	45	13	10	2	2			72	27
Am	45	34	11	15	1		1	107	73
Ac	13	5	37	3	1		8	79	42
SB	17	9		4			12	30	26
W	5				0			6	6
BSm	5	2	27			33		87	54
BSd	1	2	7			7	37	54	17
Total Fields	131	64	92	24	4	52	68	435	
Incorrect	86	30	55	20	4	19	31		249

Total Percentage Correct Identification: 43%

IMAGE #2 PAN 25A, HIGH FLIGHT
MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	44	17	4	2	4			71	27
Am	43	35	9	1				88	53
Ac	10	1	37	7		10	4	69	32
SB	20	11	6	10				47	37
W	5			1	0			6	6
BSm	5		18	2		22	5	52	30
BSd	3		18			20	59	100	41
Total Fields	130	64	92	23	4	52	68	433	
Incorrect	86	29	55	13	4	30	9		226

Total Percentage Correct Identification: 47%

IMAGE #3 IR-89B, APOLLO 9
MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	35	13		2	4			54	19
Am	46	31	11	1				89	58
Ac	25	14	54	7		10	3	113	59
SB	18	3	7	10				38	28
W	6	2	2	1	0			11	11
BSm	1		2			22	9	34	12
BSd	1		17			20	56	95	39
Total Fields	132	64	91	23	4	52	68	434	
Incorrect	97	33	37	13	4	30	12		226

Total Percentage Correct Identification: 47%

IMAGE #4 IR-89B, HIGH FLIGHT
MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	43	20	2	4	4	1		74	31
Am	38	34	16	7		1	1	97	63
Ac	13	1	38	4		3	10	69	31
SB	30	3	17	6				56	50
W	7	6	2	3	0			18	18
BSm	1		17			38	17	55	17
BSd						8	39	65	26
Total Fields	132	64	92	24	4	50	68	434	
Incorrect	89	30	54	18	4	12	29		236

Total Percentage Correct Identification: 45%

IMAGE #5 PAN 25A, HIGH FLIGHT
MAY 21, 1969

Photo Interpreter's Results	Ground Truth					tot. seen by P.I.	Com. error
	B	A	SB	BS	W		
B	113	0	2	1	0	116	3
A	1	130	15	48	4	198	68
SB	0	13	0	4	0	17	17
BS	10	12	3	59	0	84	25
W	0	1	0	8	0	9	9
Total Fields	124	156	20	120	4	424	
Incorrect	11	26	20	61	4		122

Total Percentage Correct Identification: 71%

Figure 25. Single-band/single-date images and cumulative test results for the Phoenix-Mesa, Arizona, study area.

IMAGE #9 INFRARED EKTACHROME, HIGH FLIGHT
MAY 21, 1969

Photo Interpreter's Results	Ground Truth						Tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BS		
B	108			3	4		115	7
Am		50	21	8			79	29
Ac	6	1	46	2	4	12	71	25
SB		9	17	8	4		38	30
W					0		4	4
BS	6		16	3		102	127	25
Total Fields	120	60	100	24	4	126	434	
Incorrect	12	10	54	16	4	24		120

Total Percentage Correct Identification: 72%

IMAGE #8 COLOR COMPOSITE-FRSL OPTICAL COMBINER
HIGH FLIGHT, MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							Tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	47	8		1	2			58	11
Am	57	51	15	8	2			133	82
Ac	23	3	57	8				91	34
SB	4		5	5				14	9
W	1	2		1	0			4	4
BSm			11			38	11	60	22
BSd			4			13	57	74	17
Total Fields	132	64	92	23	4	51	68	434	
Incorrect	85	13	35	18	4	13	11		179

Total Percentage Correct Identification: 58%

IMAGE #7 INFRARED EKTACHROME, HIGH FLIGHT
MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							Tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	43	17	1	4				65	22
Am	38	36	6	2				82	46
Ac	24	3	72	10				109	37
SB	24	5	2	11	0			42	31
W	2	3			0			6	6
BSm						39		39	0
BSd	1		9		4	13	67	90	23
Total Fields	132	64	90	24	4	52	67	433	
Incorrect	89	28	18	13	4	13	0		152

Total Percentage Correct Identification: 64%

IMAGE #6 INFRARED EKTACHROME, APOLLO 9
MARCH 12, 1969

Photo Interpreter's Results	Ground Truth							Tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BSm	BSd		
B	66	21	1	4				92	26
Am	31	33	2	3	2			71	38
Ac	22	5	84	10			3	124	40
SB	5	3	2	6				16	10
W	7	2		1	2			12	10
BSm						43	14	57	14
BSd	1		3			9	51	64	13
Total Fields	132	64	92	24	4	52	68	436	
Incorrect	66	31	8	18	2	9	17		151

Total Percentage Correct Identification: 65%

Figure 26. Multiband/single-date images and cumulative test results for the Phoenix-Mesa, Arizona, study area.

IMAGE #11 MULTIBAND, MULTIDATE.
EKTA AERO INFRARED (3 IMAGES)
MARCH, APRIL AND MAY

Photo Interpreter's Results	Ground Truth						Tot. seen by P.I.	Com. error
	B	Am	Ac	SB	W	BS		
B	107	1	1	2			111	4
Am	13	50	6	7	3	1	80	30
Ac	3	4	70	6		1	84	14
SB	4	9	8	8			29	21
W	1				1		2	1
BS	2		8			116	126	10
Total Fields	130	64	93	23	4	118	432	
Incorrect	23	14	23	15	3	2		80

Total Percentage Correct Identification: 81%
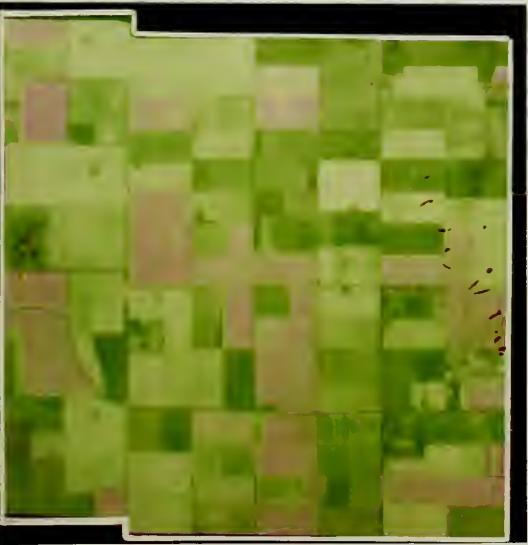
IMAGE #10 MULTIDATE COLOR COMPOSITE
FRSL OPTICAL COMBINER
HIGH FLIGHT, MARCH 12 & MAY 21, 1969

Photo Interpreter's Results	Ground Truth					Tot. seen by P.I.	Com. error
	B	A	SB	W	BS		
B	102	1	2			105	3
A	7	113	22	3	14	159	46
SB	1		0	0		4	4
W	3	3	0	0	1	5	5
BS	5	34		1	112	152	40
Total Fields	118	152	24	4	127	425	
Incorrect	16	39	24	4	15		98

Total Percentage Correct Identification: 76%

Figure 27. Single-band/multidate, multiband/multidate images and cumulative test results for the Phoenix-Mesa, Arizona, study area.
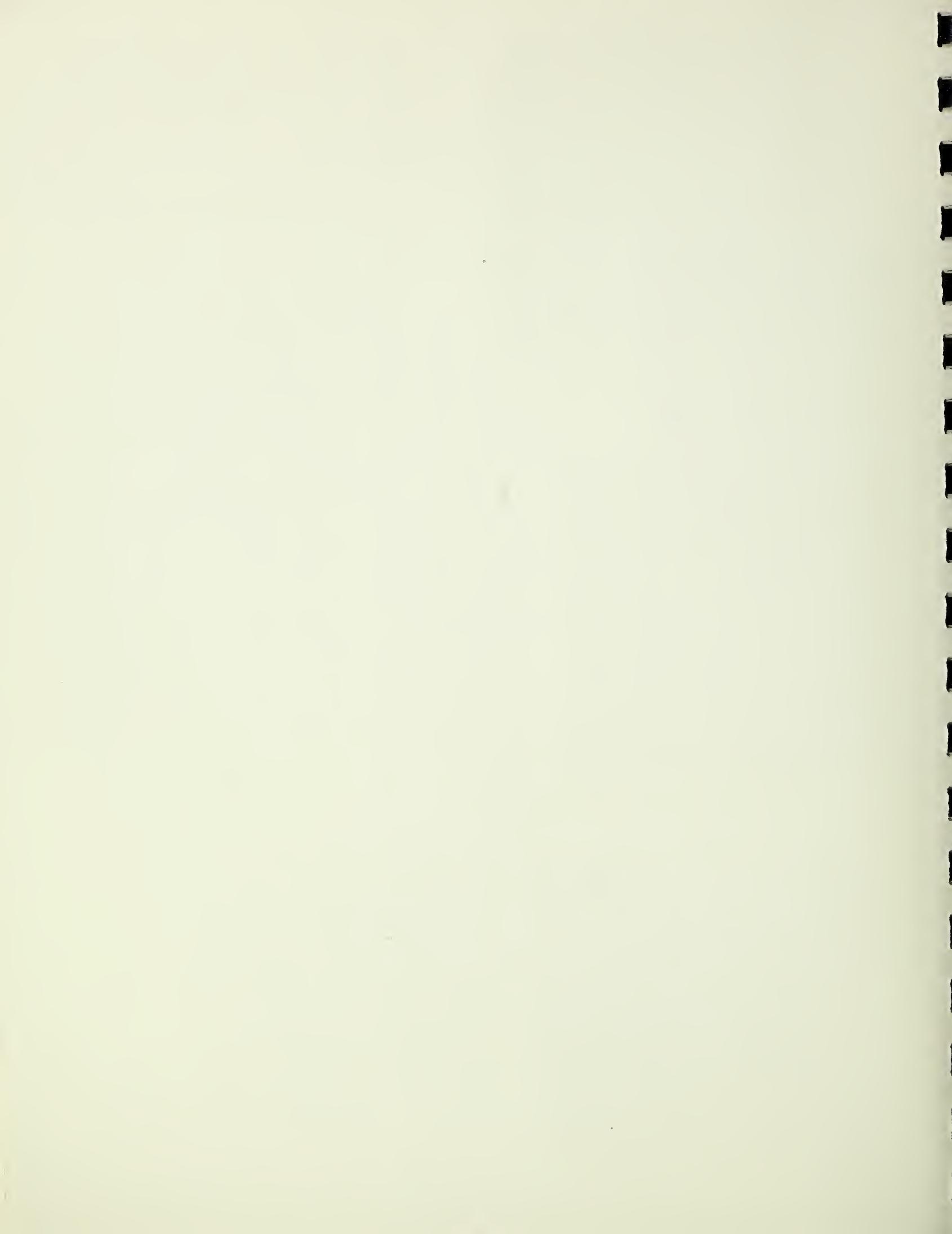
TABLE 17: TEST RESULTS FOR THE PHOENIX-MESA, ARIZONA STUDY AREA
EXPRESSED AS PERCENT CORRECT IDENTIFICATIONS FOR ALL CROP CATEGORIES

(From Colwell, et al., 1969 and Pettinger, et al., 1969.)

TEST NUMBER	INTER-PRETATION MODE	PHOTO(S)	DATE(S)	VEHICLE	PERCENT CORRECT
1	Single band; Single date	Pan-25	March	Apollo 9	43%
2		Pan-25	March	High-flight	47%
3		IR-89B	March	Apollo 9	47%
4		IR-89B	March	High-flight	45%
5		Pan-25	May	High-flight	71%
6	Multi-band; Single date	Ekta Aero Infrared	March	Apollo 9	65%
7		Ekta Aero Infrared	March	High-flight	64%
8*		Color Composite	March	High-flight	58%
9		Ekta Aero Infrared	May	High-flight	72%
10**	Single band; Multi-date	Color Composite (Pan-25)	March and May	High-flight	76%
11	Multi-band; Multi-date	Ekta Aero Infrared (3 images)	March, April and May	High-flight	81%

* A color composite image was made with the FRSL Optical Combiner using Pan-58, Pan-25 and IR-89B images projected through a blue, green and red filter, respectively.
** A color composite image was made with the FRSL Optical Combiner using March Pan-25 and May Pan-25 images projected through a violet and green filter, respectively.
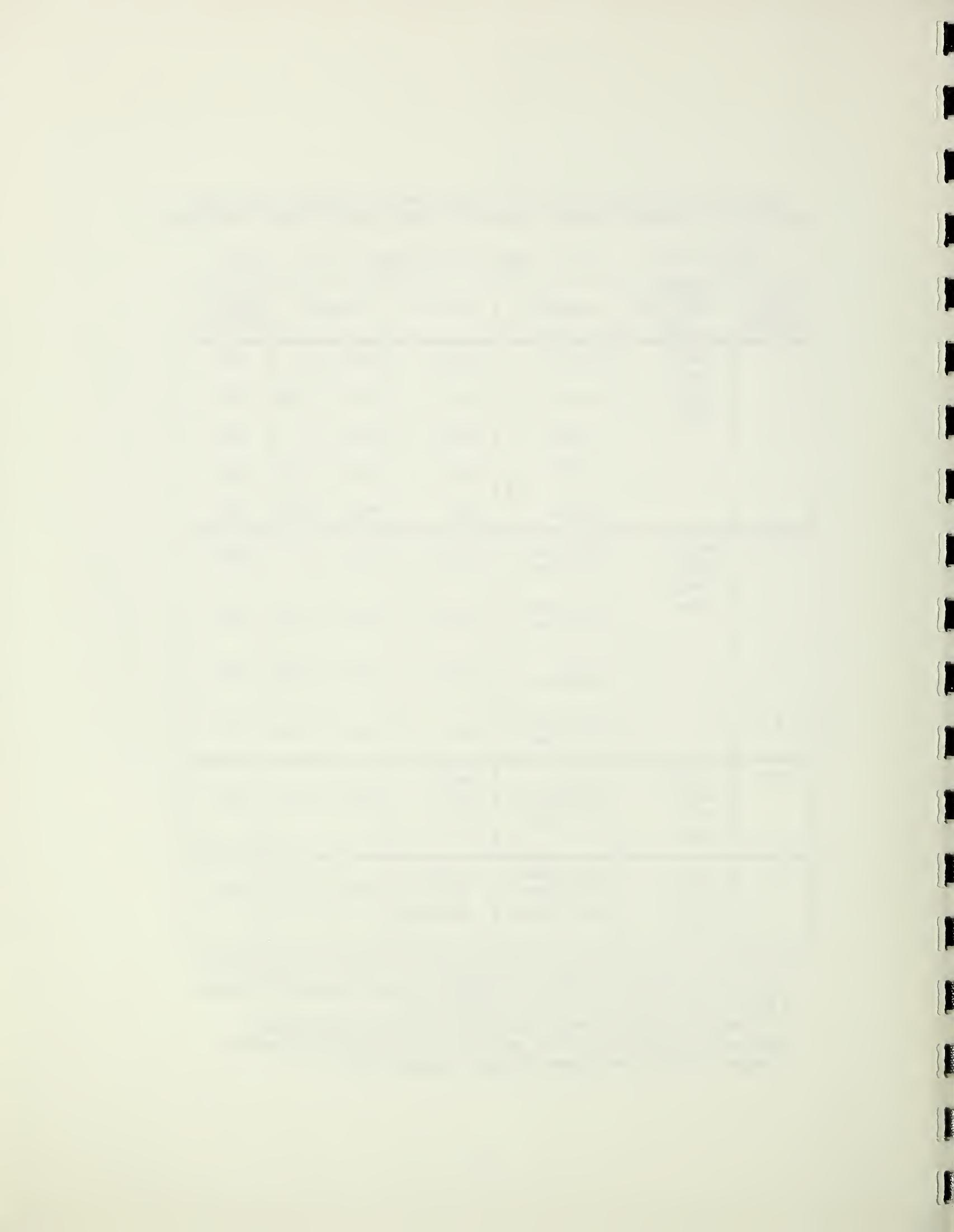
(Pan-25) taken on two different dates were viewed in a color composite form. Better results were obtained using multiband images because bare soil is most easily separated from vegetated fields on film containing an infrared sensitive band, and mature barley is best discriminated from sugar beets and alfalfa on film containing a red sensitive band.

However, the most reliable method of identifying alfalfa is that of searching for its characteristic harvest pattern on sequential images. Since alfalfa is periodically mowed (changing over time from mature to recently cut to mature), a distinct pattern for that crop is readily seen on multidate photography. Consequently, multiband/multidate photography (image 11, Figure 27) provided the maximum amount of information for identifying barley, bare soil, sugar beets and alfalfa.

Negative Density Measurements. In addition to the photo interpretation tests, high-flight multiband photography taken of the Phoenix-Mesa area was analyzed with the aid of a densitometer. As was the case in previous tests, the 16 square mile area south of Mesa, Arizona, was chosen for study. Again, this decision was based on the fact that good ground truth information was available for the entire area for each overflight and thus quantitative evaluations could be made of the imagery.

Eleven images were selected for measurement: Pan-25 in March, April, May and September; Pan-58 in March, April, May and September; and IR-89B in March, April and September (the IR-89B camera malfunctioned during the May flight). These images, covering the basic broad bands of the spectrum, i.e., green, red and near infrared, were found to be most useful for aiding in crop identification. The four dates selected cover a wide time dimension, allowing crop phenology to aid in identifying crop type.

Density, expressed as percent transmission, was measured for five rep-resentative fields of each crop type on each of the 11 frames of photography.
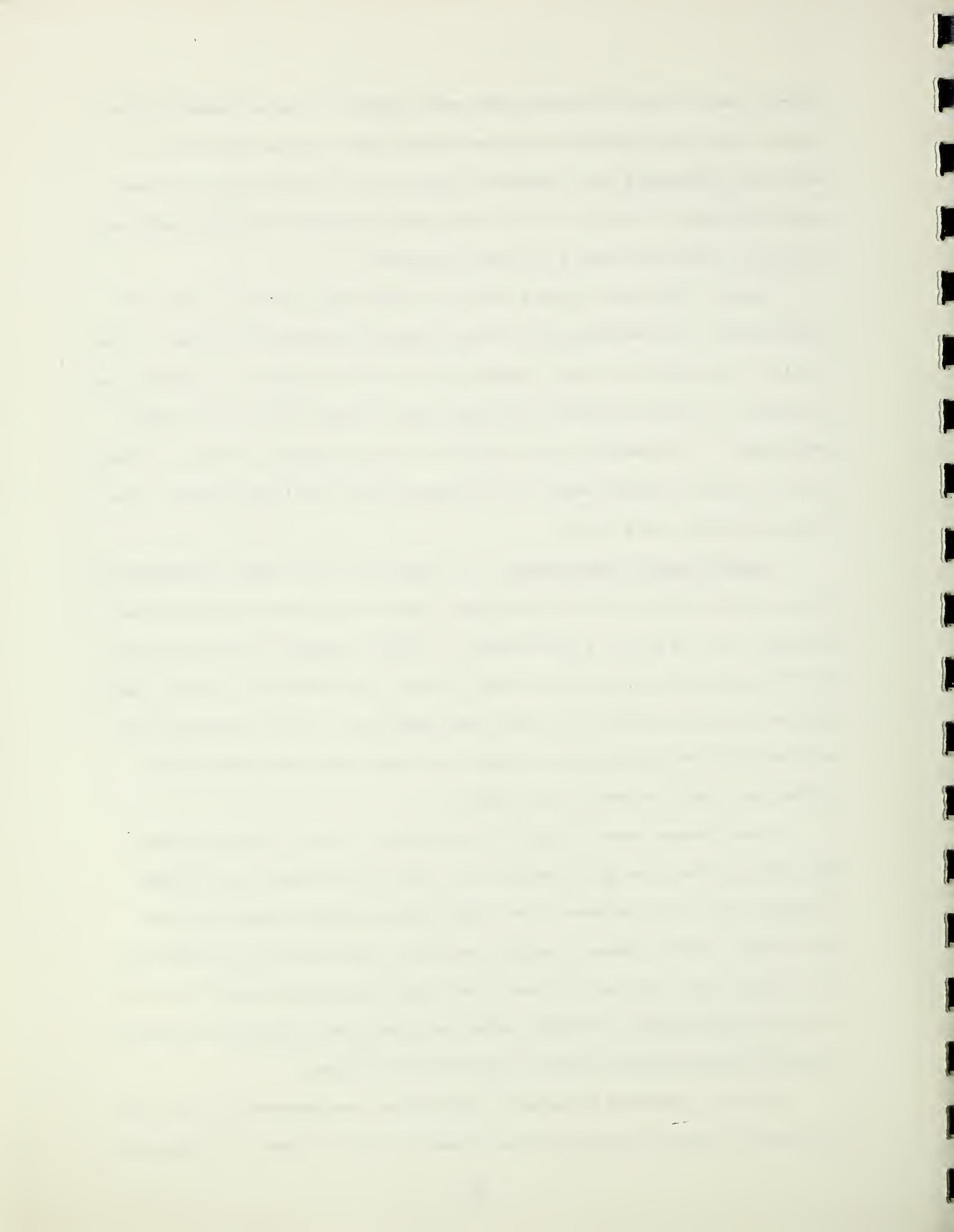
The measurements were made using a Welsh Densicron (1 mm aperture). An analysis of variance was performed on the percent transmission data for each photograph. If significant differences occurred, the data were then analyzed using Duncan's new multiple range test to determine where statistically significant differences existed among the ranked means of percent transmission for the different crop types (see Tables 18 - 20)..

A conclusion similar to the one drawn from the Davis tests can be made regarding the results shown here--no single film/filter combination can be used to discriminate among all crops. By using two or more film/filter combinations in concert, however, a greater number of discriminations can be made. When additional dates are included in the analysis, it is possible to identify nearly all crop types. For example, the use of three images allows us to discriminate the six major crop types or field conditions within the 16 square mile study area. Sugar beets and bare soil (moist and dry) can be identified on March Pan-25; cotton and milo are easily separated from everything else on April Pan-25; barley is best discriminated in May Pan-58; and alfalfa (cut and mature) can be extracted from these three images analyzed in concert since it is the only major crop remaining (on all film/filter combinations mature alfalfa and sorghum are not distinguishable; however, sorghum is not nearly as important or abundant in this region as is alfalfa).

Electronic Enhancements. These same 11 B/W multiband images were electronically scanned and color combined using the IDECS system at the University of Kansas (the system has been briefly described above). The objective of this exercise was to determine whether a skilled operator could extract, with the aid of the IDECS system, as much information on agricultural crop types as did the human photo interpreters given the same imagery. Since one of the advantages of an electronic enhancement device is its extreme

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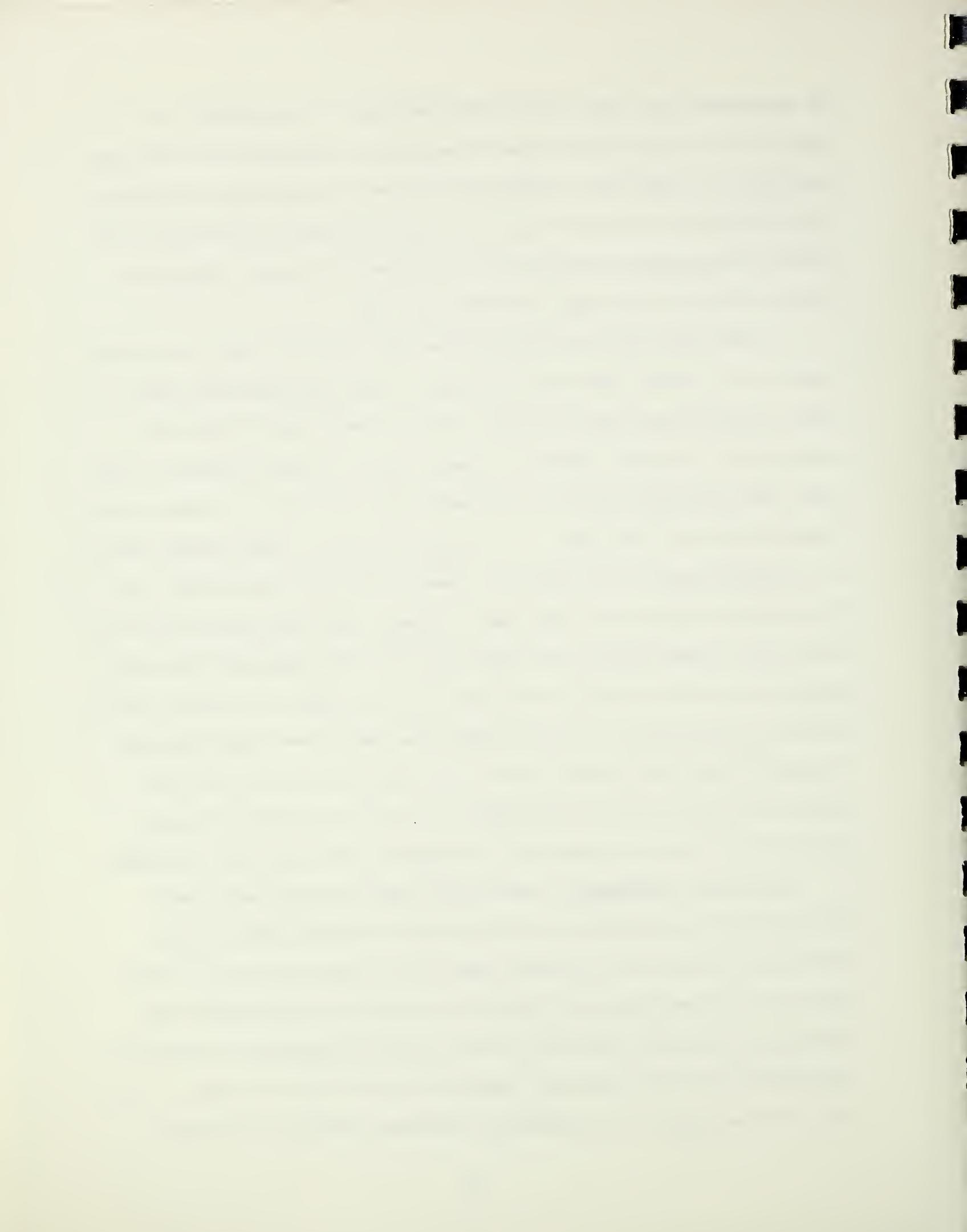
TABLE 18: PANCHROMATIC-25; MEAN PERCENT TRANSMISSION IN RANKED ORDER

DATE	CROP	RANKED MEANS (.05)	HOMO. GROUP(S)
March	B	29.8	
	Am	28.2	
	Ac	27.6	
	SB	20.0	
	BSm	16.0	
	BSd	11.0	
April	W	33.8	
	SB	33.2	
	Am	32.2	
	B	29.6	
	M	22.2	
	C	17.8	
May	Am	29.2	
	Ac	28.4	
	M	27.8	
	SB	27.0	
	C	23.4	
	B	16.6	
September	S	17.8	
	Am	17.2	
	C	15.4	
	M	13.6	
	BSm	8.4	
	Ac	7.4	
	BSd	6.6	

LEGEND

B	=	barley
Am	=	alfalfa, mature
Ac	=	alfalfa, cut
SB	=	sugar beets
BSm	=	bare soil, moist
BSd	=	bare soil, dry
W	=	wheat
M	=	milo
C	=	cotton

TABLE 19: PANCHROMATIC-58; MEAN PERCENT TRANSMISSION IN RANKED ORDER

DATE	CROP	RANKED MEANS (.05)	HOMO. GROUP(S)
March	SB	22.4	
	B	22.0	
	Am	21.8	
	BSm	21.2	
	Ac	20.2	
	BSd	17.8	
April	SB	19.0	
	Am	18.0	
	Ac	17.6	
	B	16.8	
	M	15.6	
	C	15.2	
	BSd	13.5	
May	SB	15.6	
	Ac	15.4	
	Am	15.0	
	M	15.0	
	C	14.4	
	B	8.8	
September	S	16.4	
	Am	15.8	
	C	15.2	
	M	14.6	
	BSm	8.8	
	Ac	7.6	
	BSd	6.4	

LEGEND

B	=	barley
Am	=	alfalfa, mature
Ac	=	alfalfa, cut
SB	=	sugar beets
BSm	=	bare soil, moist
BSd	=	bare soil, dry
W	=	wheat
M	=	milo
C	=	cotton
S	=	sorghum

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TABLE 20: INFRARED-89B; MEAN PERCENT TRANSMISSION IN RANKED ORDER

DATE	CROP	RANKED MEANS (.05)	HOMO. GROUP(S)
March	BSm	14.6	
	BSd	9.2	
	Ac	6.6	
	SB	5.4	
	Am	3.8	
	B	3.2	
April	M	20.6	
	C	20.0	
	BSd	19.0	
	Ac	15.0	
	SB	14.8	
	B	14.4	
	Am	14.2	
May	Not Available		
September	M	23.3	
	BSm	23.2	
	BSd	22.2	
	Ac	20.2	
	S	18.6	
	Am	18.0	
	C	17.6	

LEGEND

B	=	barley
Am	=	alfalfa, mature
Ac	=	alfalfa, cut
SB	=	sugar beets
BSm	=	bare soil, moist
BSd	=	bare soil, dry
W	=	wheat
M	=	milo
C	=	cotton
S	=	sorghum

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flexibility (e.g., fast scan rates, rapid data storage and retrieval, image display via programmed "additive" and "subtractive" algorithms); and since, in addition, significant differences existed between crop type tone densities within the images, the probability of succesful discrimination between crops on the IDECS system was high.

Pan-25 images taken in April, May and September were used since only two scanners were functioning at the time of this study. Density slices were made for a different target on each of the following images or combination of images, and the data were stored on a computer disc for subsequent manipulation and retrieval (see Table 21).

The stored data were then selectively retrieved and algorithms available with the IDECS system were applied to these data in an attempt to color code each of the six major cropland categories found in the 16 square mile area. The procedure used to create each of the enhanced images is give in Table 22.

Note that a distinct color was assigned to each major cropland category except alfalfa. However, since nearly everything else in the area had been color coded, that which remained black was assumed to be alfalfa. The six color enhanced images are shown in Figures 28 and 29, along with corresponding ground truth data.

To evaluate the effectiveness of the IDECS enhancements for crop identification, the color coded images shown in Figures 28 and 29 were compared with the corresponding ground truth data and the fields correctly and incorrectly color coded were tabulated (see Table 23).

It is difficult to draw meaningful conclusions from these results since the study was performed only on a limited area. Nevertheless, the results are certainly encouraging. Acceptable accuracies (75 percent) in terms of percent

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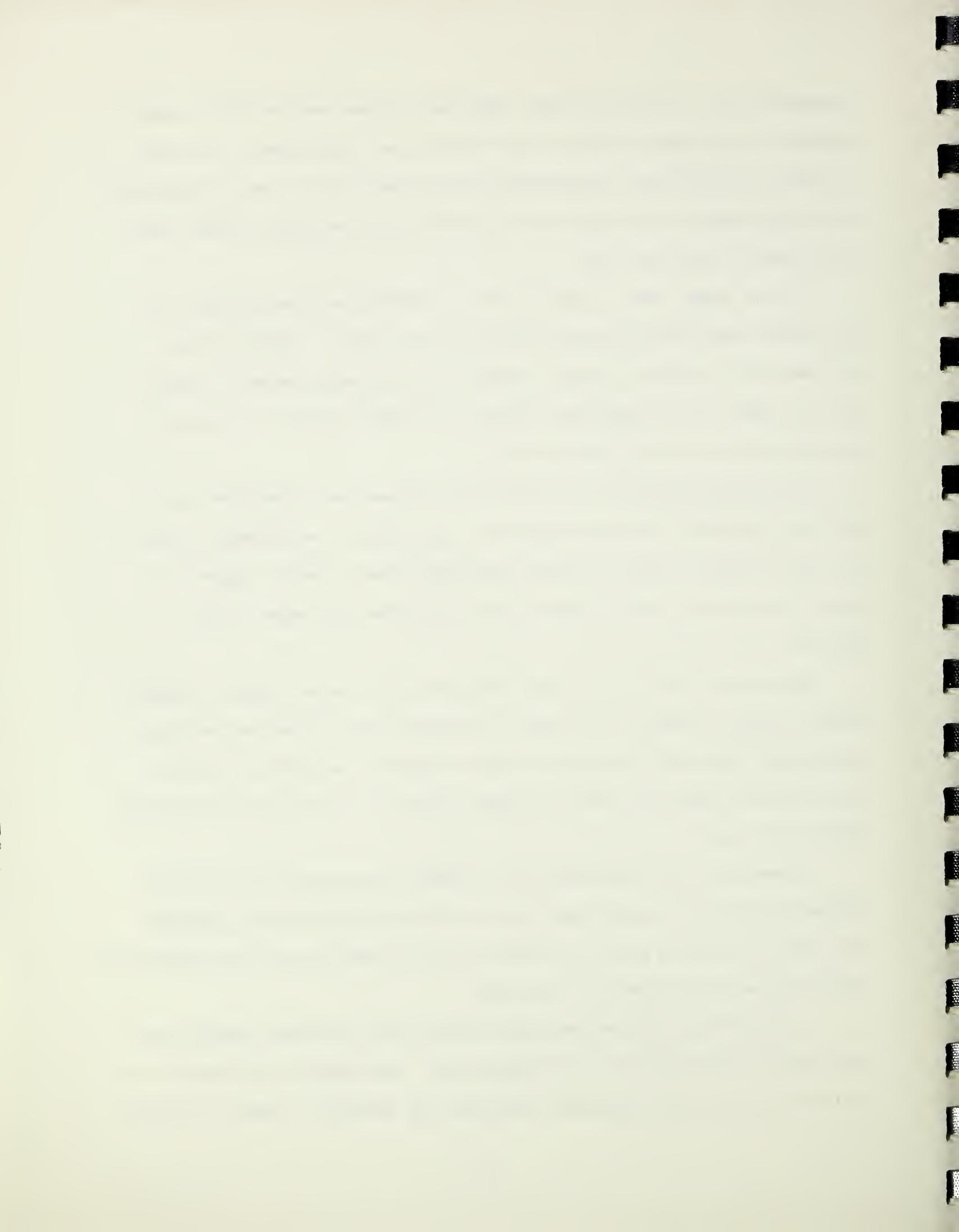
TABLE 21. DATA ON MAJOR CROPLAND CATEGORIES, EXTRACTED FROM SINGLE-BAND, MULTIDATE IMAGERY; PHOENIX-MESA, ARIZONA.

DATE	SUBJECT	METHOD	CHANNEL
April	Cotton and urban	Iso-density slice	16
May	Barley	''	9
Sept.	Bare soil (previously barley or sugar beets) and urban	''	15
April and Sept.	Urban	Ch. 16 and Ch. 15	10
May and Sept.	Bare soil (previously barley)	Ch. 9 and Ch. 15	17
May and Sept.	Barley and bare soil (previously barley)	Ch. 9 and Ch. 17	14

TABLE 22. PROCEDURE EMPLOYED TO ELECTRONICALLY ENHANCE AND COLOR DISPLAY EACH
MAJOR CROPLAND CATEGORY; PHOENIX-MESA, ARIZONA.

ENHANCEMENT NUMBER	SUBJECT(S)	COLOR(S)	CHANNEL(S)
1	Barley	Orange	9
2	Cotton (urban)	Purple (white)	10 + 16
3	Urban	White	10
4	Sugar beets (bare soil formerly barley, and urban)	Rust (white and blue)	15 + 17 ÷ 10
5	Sorghum (bare soil that was barley)	Violet (white)	14 + 17
6	Alfalfa	Black	all of the above
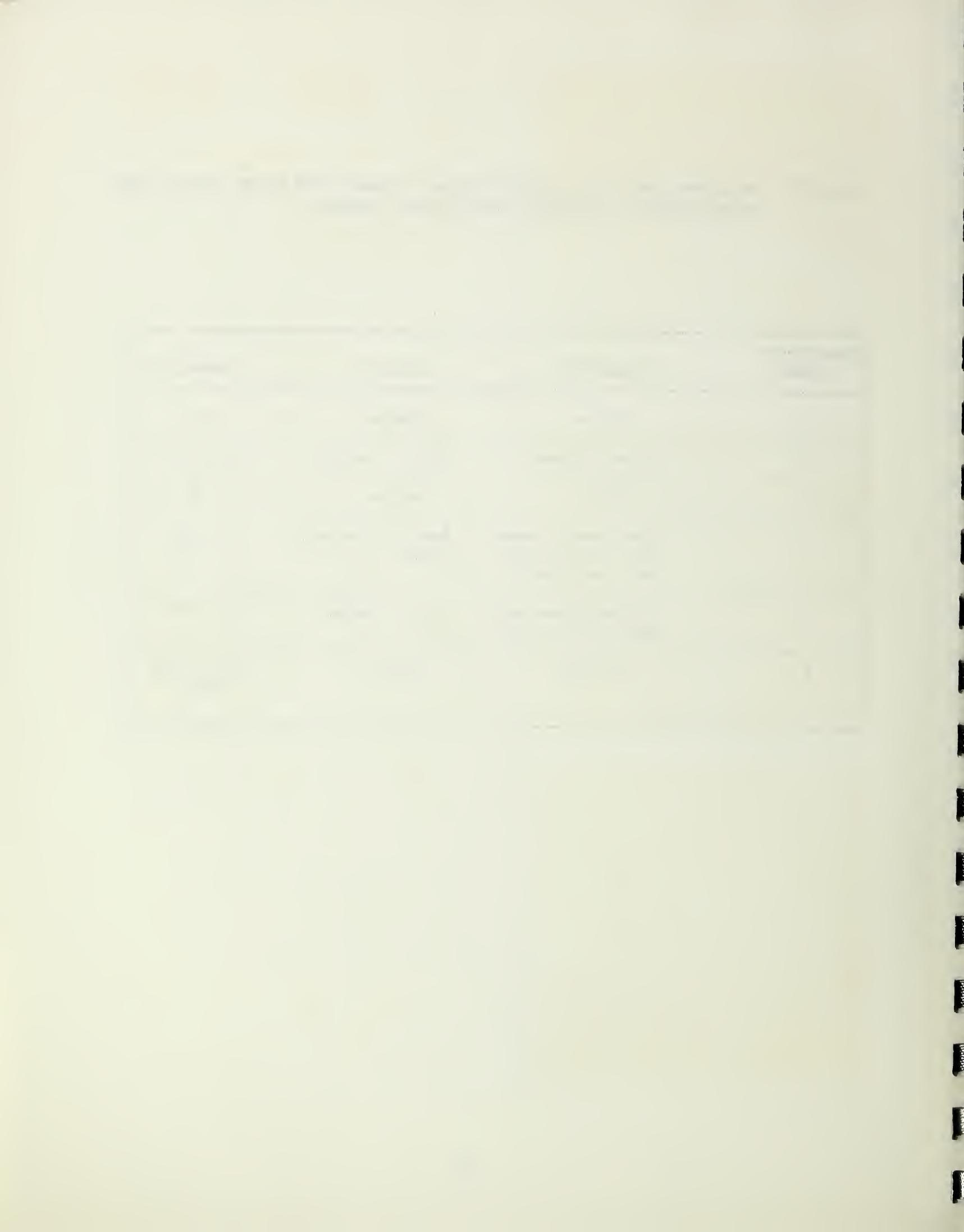
Barley = red
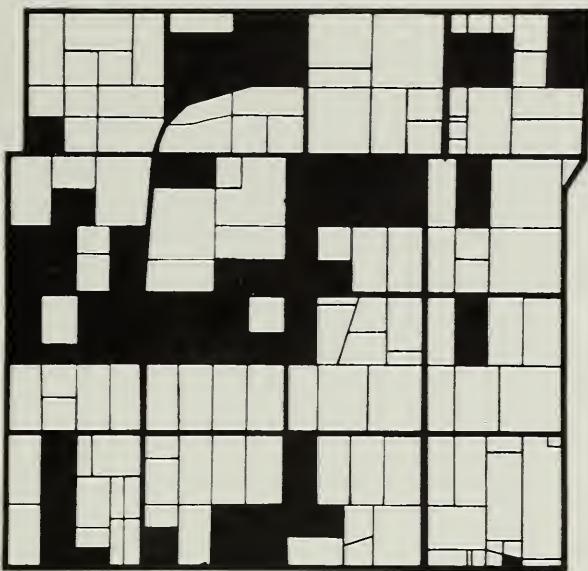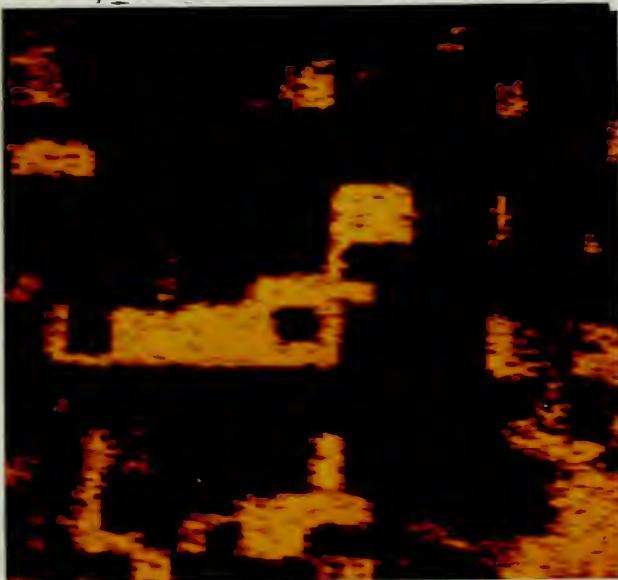
Cotten = purple
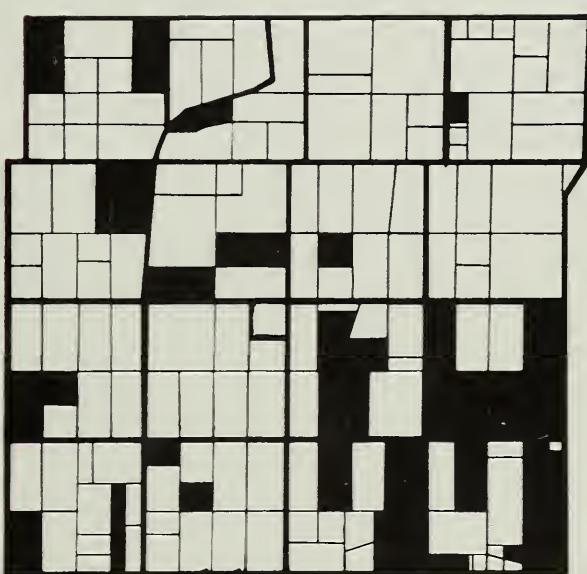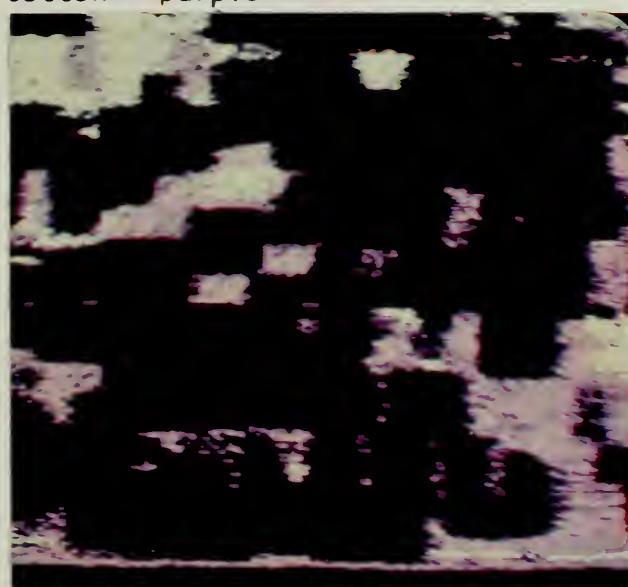
Urban = white
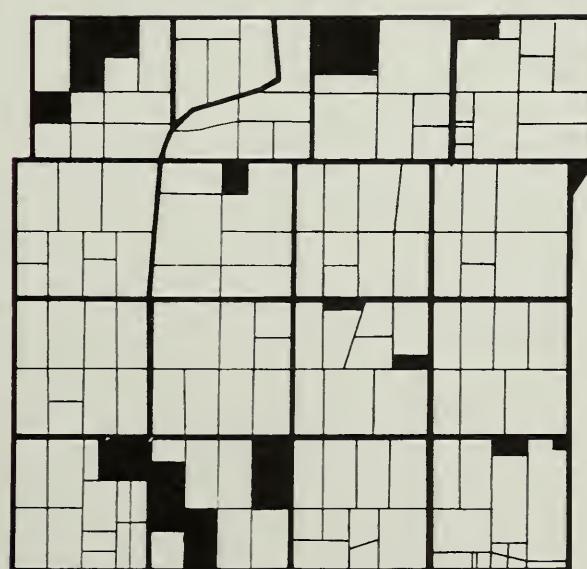
Figure 28. Electronically enhanced imagery of the Phoenix-Mesa study area made with the IDECS system. See text for explanation.
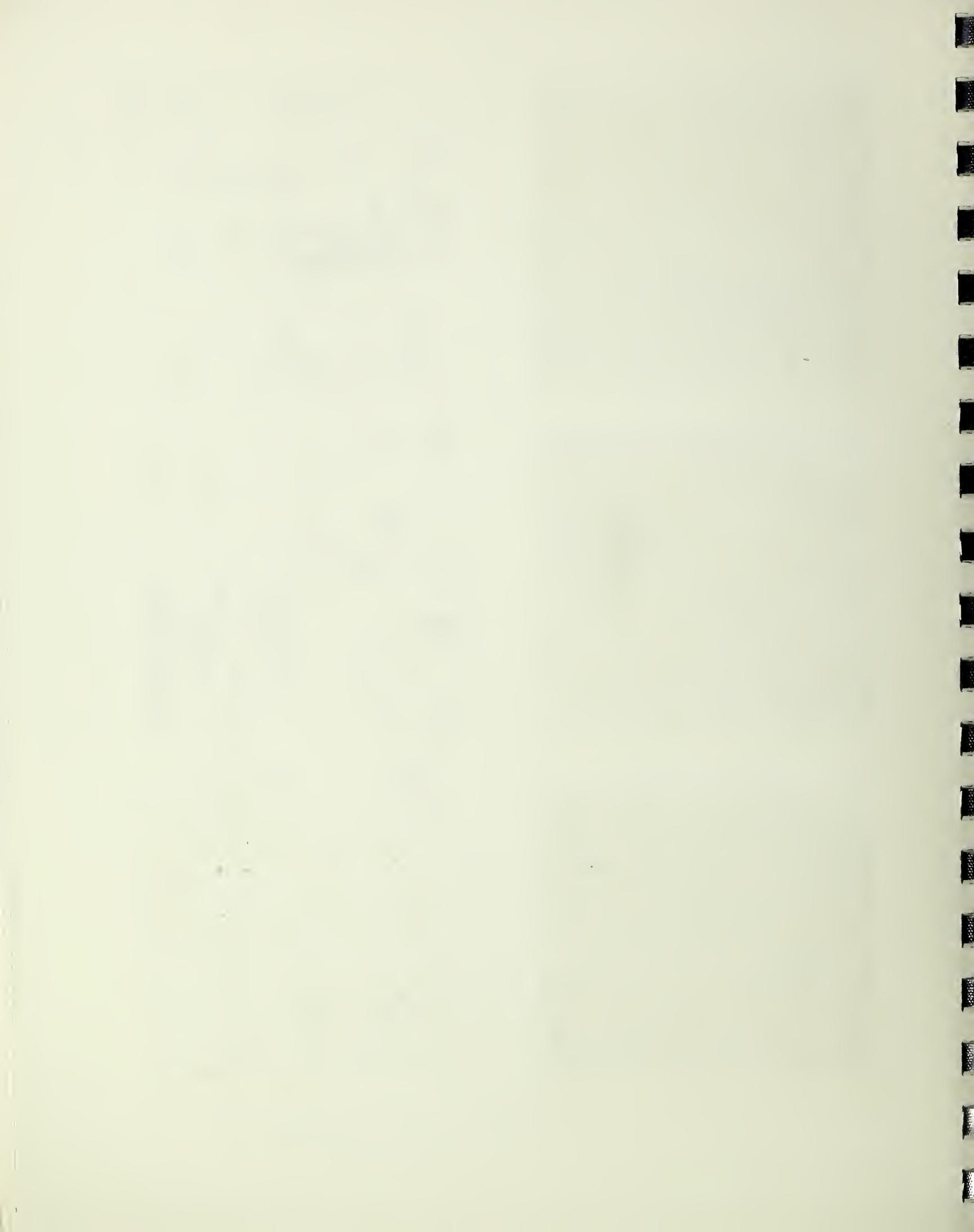
Sugar Beets = rust
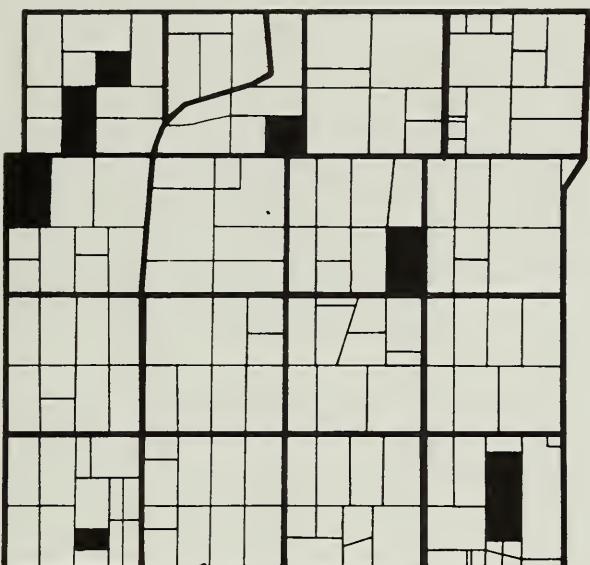
Sorghum = violet
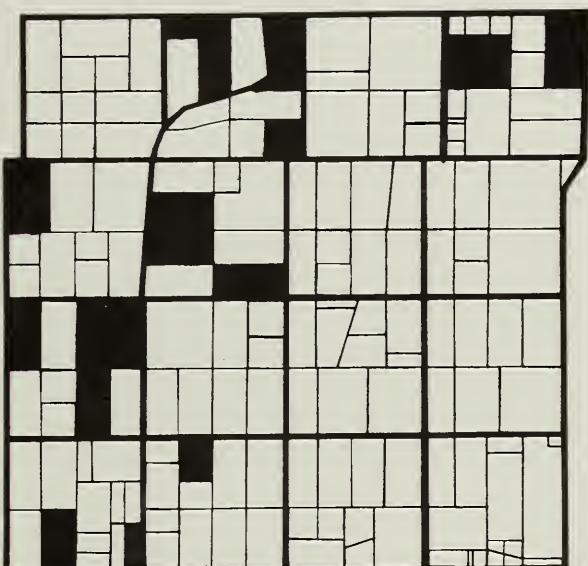
Alfalfa = black
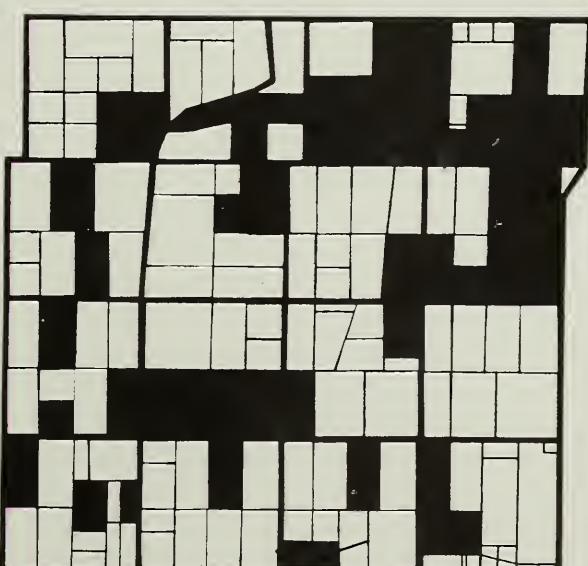
Figure 29. Electronically enhanced imagery of the Phoenix-Mesa study area made with the IDECS system. See text for explanation.

TABLE 23. EFFECTIVENESS OF ELECTRONIC ENHANCEMENTS FOR CROPLAND IDENTIFICATION;
          PHOENIX-MESA, ARIZONA.

CROP TYPE	ENHAN. #	TOTAL FIELDS	FIELDS CODED WITH COLOR	FIELDS COR-RECTLY CODED	FIELDS OMITTED	FIELDS COMMITTED	% CORR.	% COMM.
Barley	1	39	35	30	9	5	76.9	14.3
Cotton	2	33	45	31	2	16	90.0	35.6
Urban	3	15	13	6	9	13	40.0	100.0
Sugar Beets	4	8	19	6	2	20	75.0	105.3
Sorghum	5	16	28	8	7	21	50.0	75.0
Alfalfa	6	43	68	37	6	31	86.0	45.6
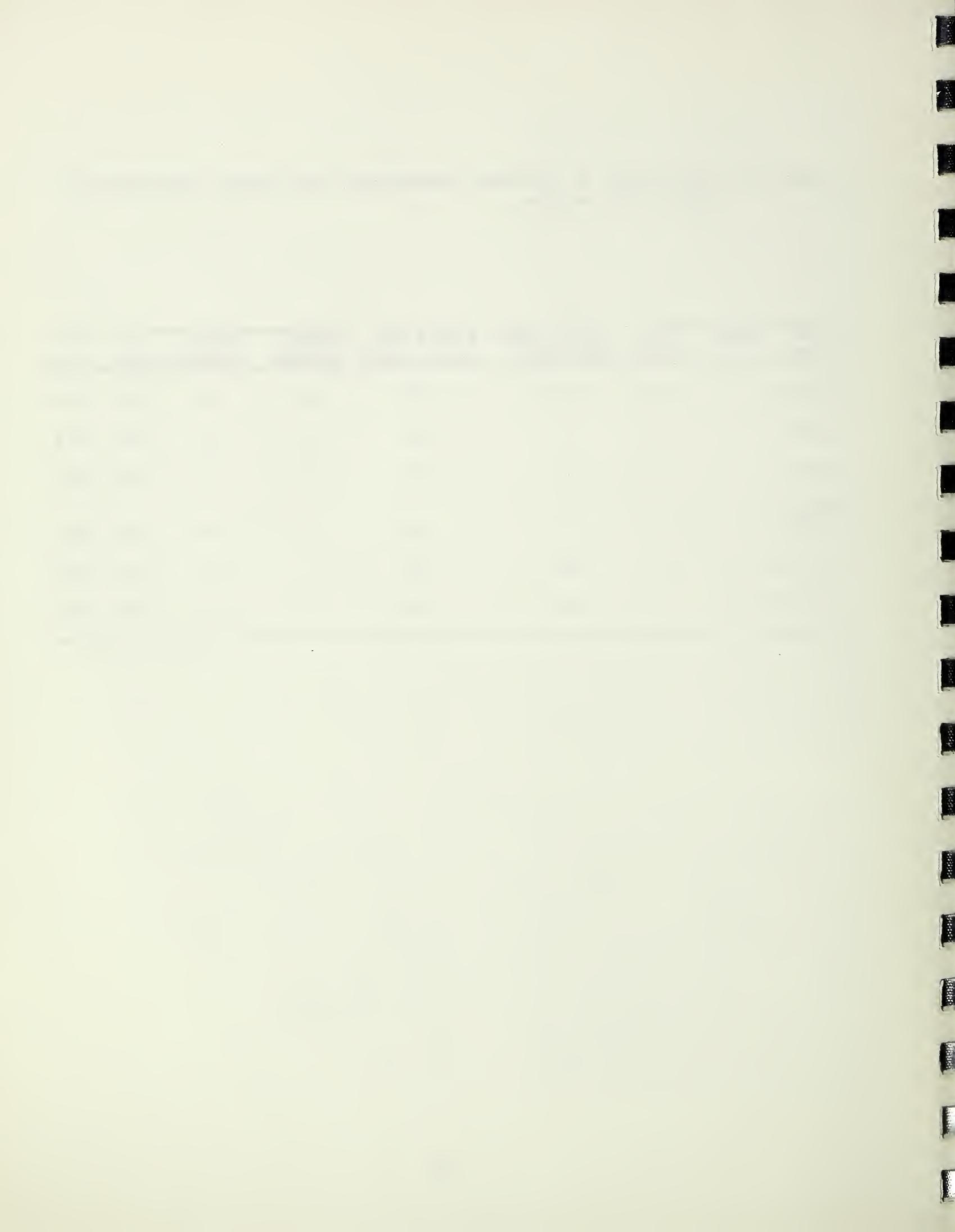
TABLE 24. PERCENT CORRECT AND PERCENT COMMISSION ERROR RESULTS DERIVED BY
PHOTO INTERPRETATION (TESTS) AND BY ELECTRONIC IMAGE ENHANCEMENT
(COLOR CODE) FOR CROPLAND DISCRIMINATION; PHOENIX-MEXA, ARIZONA.

CROP TYPE	PHOTO INTERPRETATION		IDECS COLOR CODES	
	% CORRECT	% COMM.	% CORR.	% COMM.
Barley	82	4	77	14
Alfalfa	83	21	86	46
Sugar beets	35	72	75	105
Cotton	84	10	90	36
Sorghum	46	39	50	75

correct (color code) were obtained for all cropland categories except urban and sorghum. Since much of the urban area was actually part of the University of Arizona agricultural farm and some developed areas were planted with lawns, the urban areas were often categorized as a vegetative type. Sorghum, sugar beets and alfalfa were, as was the case in the photo interpretation tests, the most difficult crop types to identify. It is interesting to note that the photo interpreters' results and IDECS color coded results for this same area were quite similar in terms of percent correct identification; however, in terms of percent commission error, the photo interpreters' results were superior. Percent correct and commission error results for both methods (human photo interpretation and electronic image enhancement) are given in Table 24.

This study seems to indicate that the flexibility afforded by an electronic enhancement system, which allows the operator to add and subtract various combinations of isodensity data derived from both multiband and multi-date images, can be an effective aid in discriminating among agricultural crop types.

SUMMARY OF RESULTS

The research reported upon above represents a quantitative evaluation of current techniques used in the acquisition and interpretation of multiband photography. Determinations have been made of the relative value for extracting useful resource information of single-band photography, multiband color and false-color infrared photography, and multiband black-and-white photography combined into false-color enhancements.

100
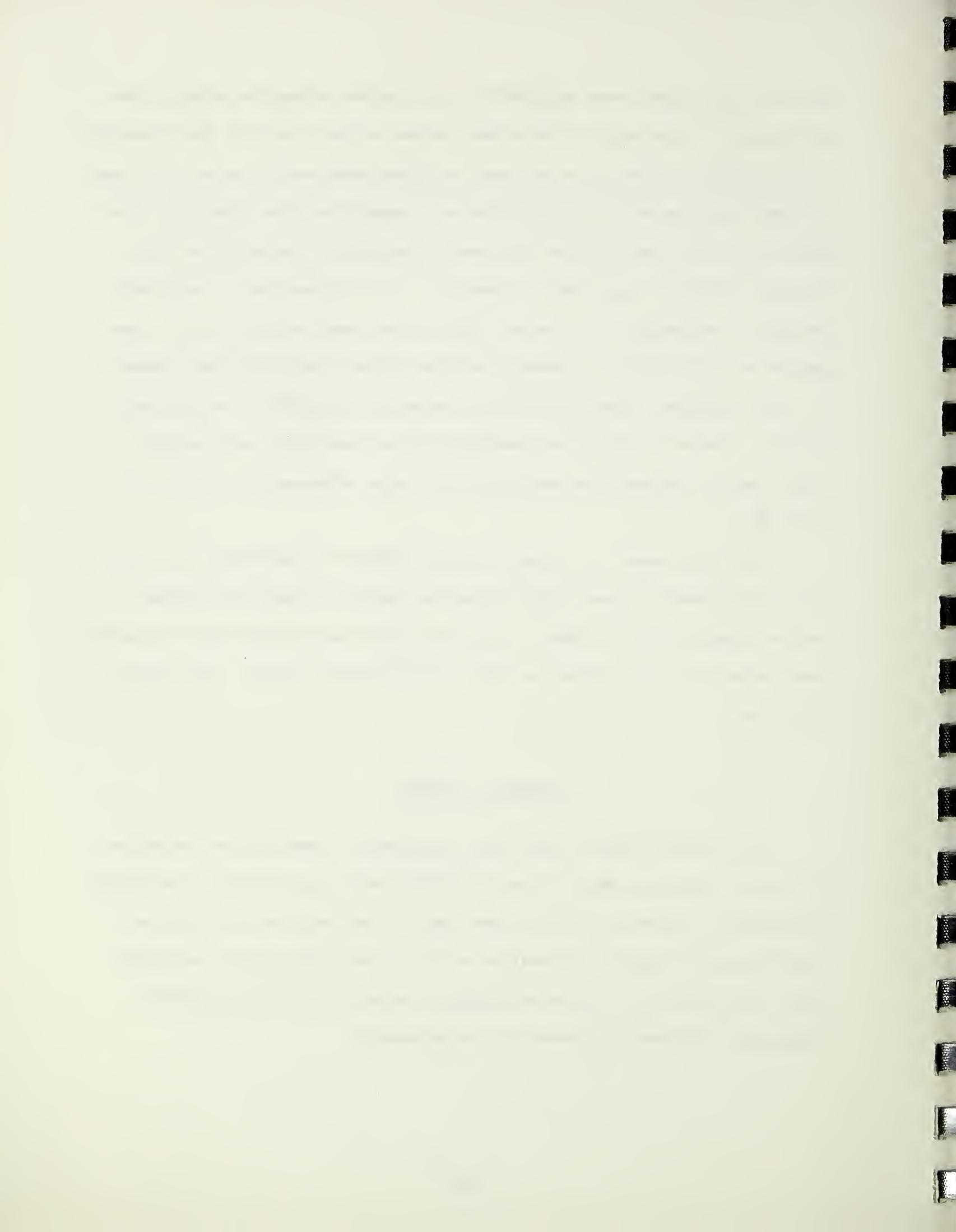
Interpretation testing procedures were applied to the photography acquired of forested lands at Yosemite Valley and Bucks Lake, California, and agricultural lands at Davis and Imperial Valley, California, and Phoenix-Mesa, Arizona. In addition, negative density measurements were made on multiband images containing selected examples of known terrain features and the results were quantitatively analyzed (Davis, Imperial Valley and Phoenix-Mesa). Furthermore, multiband images of agricultural resources were combined and enhanced by electronic means and the composite images were evaluated in terms of information content.

The results of the interpretation tests were compiled, compared with ground truth data and tabulated. The test results were subjected to statistical analyses, when applicable. Significant findings obtained for each case study are presented below:

<u>Yosemite Valley, California</u>: Possibly the most encouraging results supporting the use of multiband B/W photography were found in this case study. While individual forest tree species were not consistenly identifiable on any of the image types tested, in the case of an important forest type, coniferous trees, a carefully selected set of narrow band black-and-white images was superior. These images (peak transmissions at 553 nm, 682 nm and 754 nm), when projected through red, blue, and green filters, respectively, gave significantly better percent correct identification results than all other image types tested. In addition, in every test except one, the two types of single-band imagery ranked lowest for tree type identification and the narrow band enhancement, in all cases but two, ranked highest for this purpose.

<u>Bucks Lake, California</u>: The results of tests carried out on imagery

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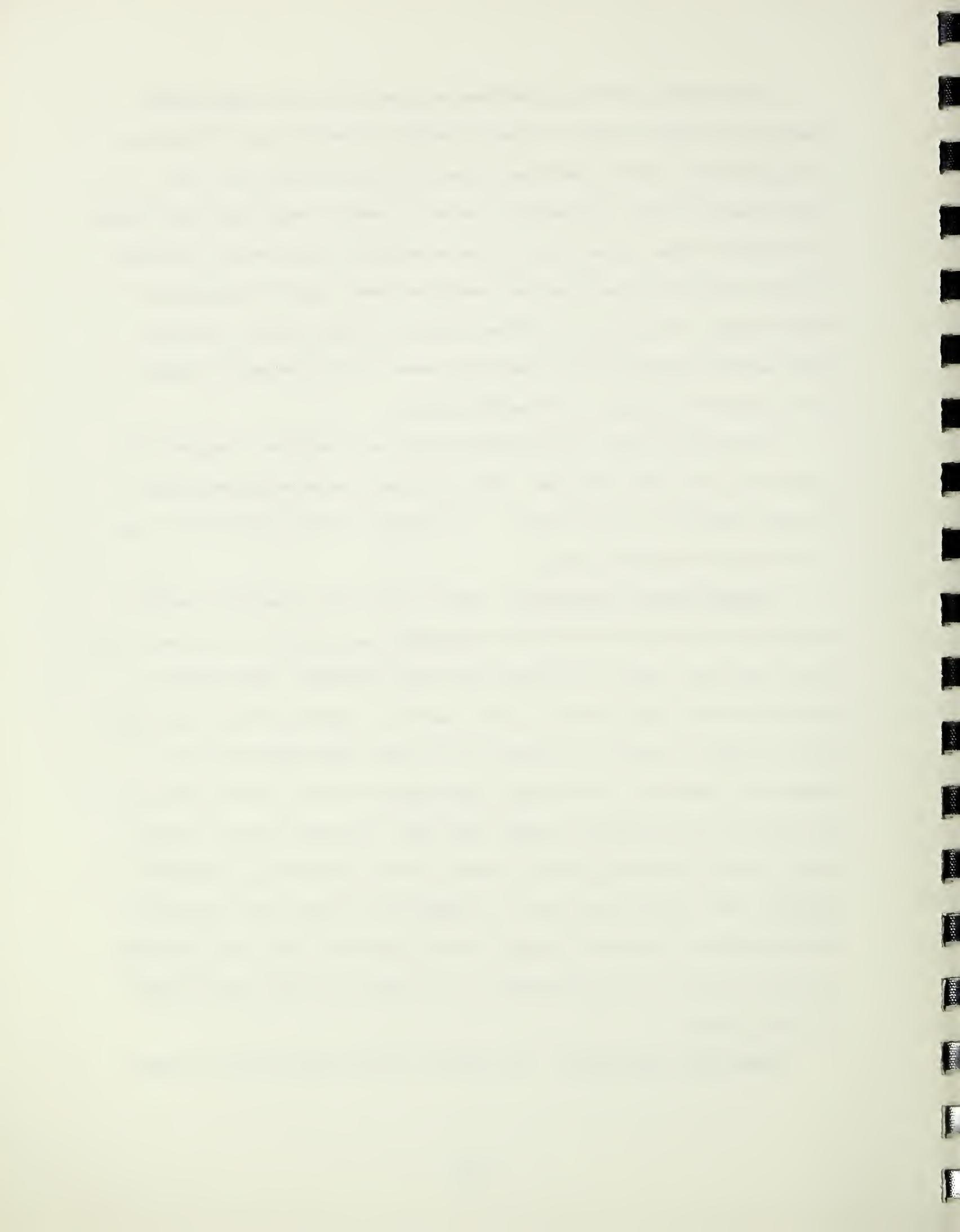
of the Bucks Lake test area indicate that skilled photo interpreters can accurately categorize six different forest resource types (medium-high density timber, low density timber, brush and dry site hardwoods, riparian and meadow vegetation, bare soil or rock, and water bodies) with a high degree of accuracy, i.e., high percent correct identification and low percent commission error. Only on two types of imagery, IR-89B and a broad band enhancement (green, red and near infrared bands projected through blue, red and green filters, repectively) were problems encountered in identifying resource types. These results emphasize the fact that band selection and enhancement procedures must be carefully evaluated. Not all enhancements of multiband imagery are going to provide additional information; in fact, information frequently can be reduced by the enhancement procedure if improperly applied.

Davis, California. Multiband photographs sequentially obtained over a target array of agricultural crops were measured with the aid of a densitometer. In an attempt to discriminate between crops (alfalfa, tomato, potato, milo, safflower, wheat, barley, sugar beets and cotton) the density data were statistically compared. The analysis of the results indicates that no single film/filter combination could be used to identify all crops in the target array. By increasing the bands of photography, however, more discriminations could be made. Furthermore, additional gains were made in discriminating among crops when utilizing multidate photography. After extensive testing of numerous bands and dates of photography, it was found that a particular combination of bands and dates, although probably not unique, gave complete statistical discrimination between all crops tested-- Pan-25 on July 17, Pan-25 on August 14 and IR-301+58 on July 25.
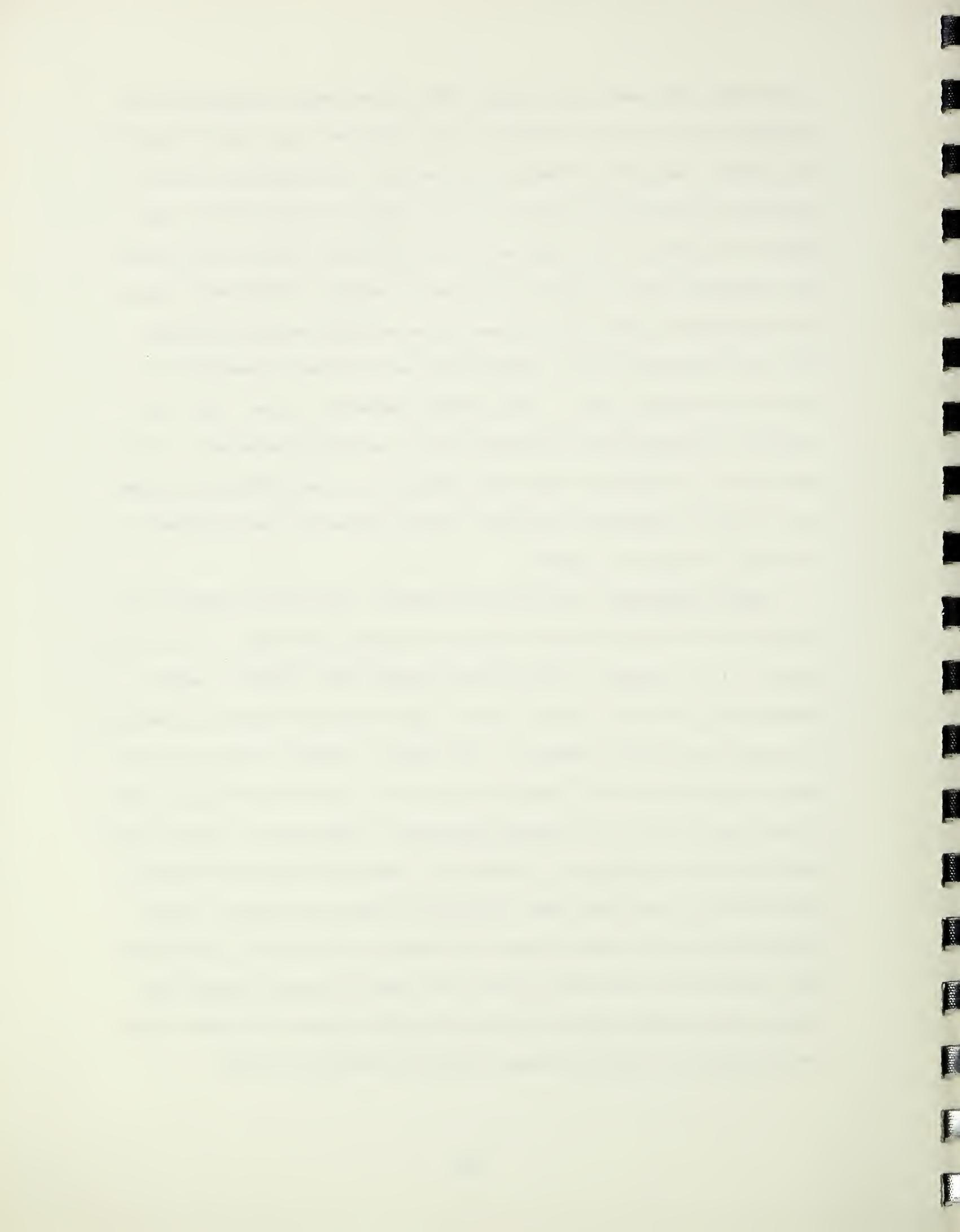
Imperial Valley, California: Interpretation tests were performed on various types of imagery taken on a single date. It was concluded that if given the task of classifying the important agricultural crops in Imperial Valley with single date (July) photography, multiband rather than single-band photographs would be more useful. Moreover, color composite multiband photos consistently yielded as much information on crop categories as color and false-color infrared films.

An additional test was performed on the set of single-band photos (IR-301+25) whereby the imagery was analyzed by two groups of interpreters displaying different levels of skill. In this case, the more experienced and skillful group obtained results that were significantly better than those of the less skillful group.

Lastly, analysis of microdensitometer data derived from the Imperial Valley photography indicated that the green band, displayed less variability within fields than did the red band, thus provided more reliable crop discrimination information. However, the high degree of variability within crop types seen on both bands, the green and the red, hindered accurate crop identification.

Phoenix-Mesa, Arizona: The photo interpretation tests performed on Apollo 9 and high altitude photographs taken of a 16 square mile area near Mesa, Arizona, further supported the findings of the previous studies involving agricultural inventories. Single-band/single-date photos produced the lowest results. Improved results were obtained when either multiband or multidate photography was employed. However, multiband/multidate photography (three separate color infrared photos taken in March, April and May and viewed in concert) provided the maximum amount of information for identifying the four major cropland categories present--barley, bare soil, sugar beets and alfalfa.

In addition, negative density measurements made on broad band, multidate
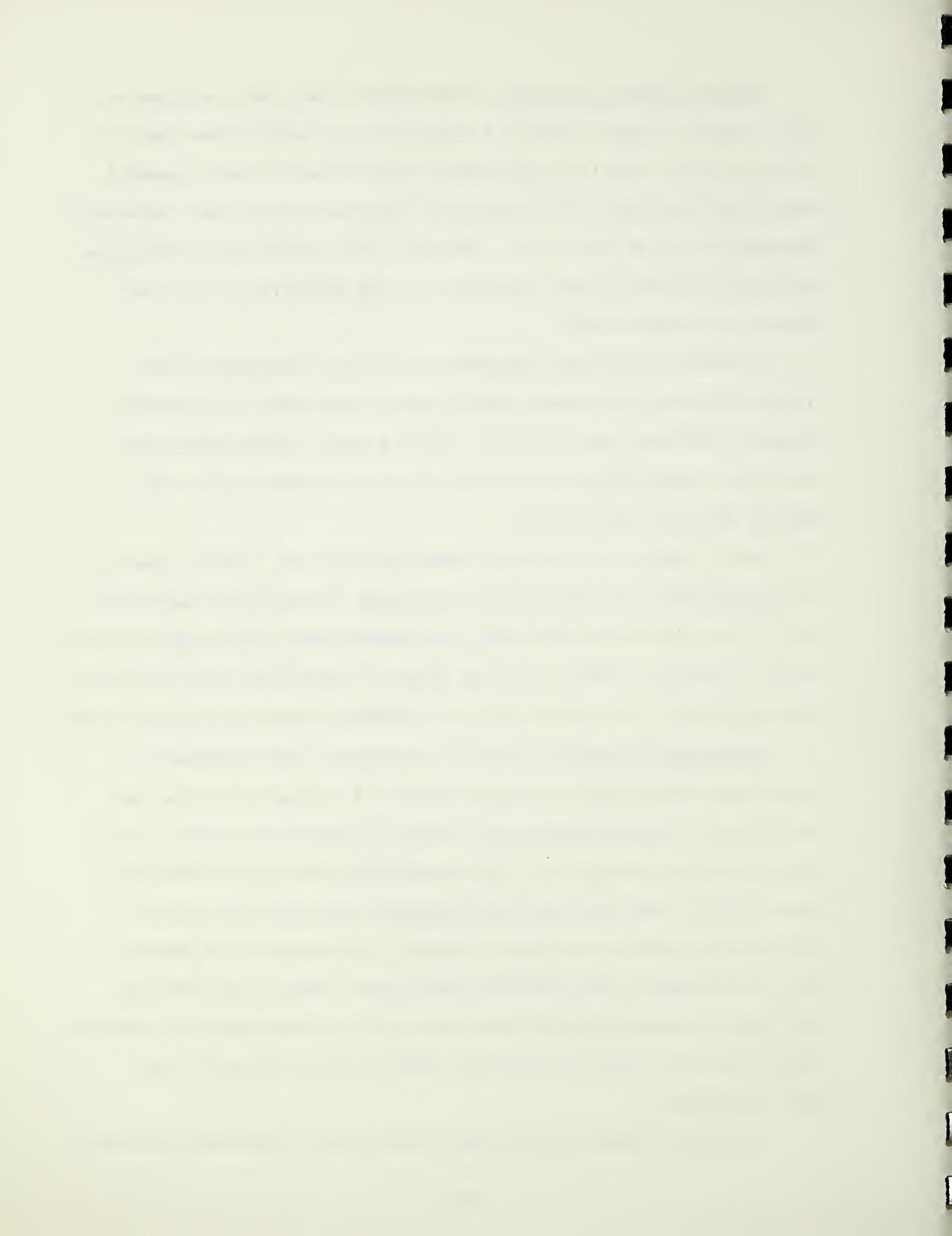
photography (similar dates) further supported these findings. Quantitative
analyses of optical density data for each crop type indicated that all
categories could be discriminated on Pan-25 (March), Pan-25 (April), and
Pan-58 (May).

Lastly, multiband/multidate images of the 16 square mile area were
electronically enhanced on IDECS. Although quantitative data analysis was
not possible, the great potential of such an enhancement system, in partic-
ular the flexibility of data storage, retrieval, compression and display,
was aptly demonstrated in terms of color coding and discriminating between
agricultural crops in the Phoenix-Mesa area.

CONCLUSIONS

The theoretical arguments for the use of multiband photography have
been the topic of spirited discussion for quite some time. Responsive to
this theoretical potential, highly effective multilens cameras and multiple
camera arrays have been developed which are capable of acquiring high qual-
ity, calibrated multiband photography. Nevertheless, a quantitative assess-
ment of the advantages and disadvantages of such photography has been diffi-
cult to achieve. The series of experiments described in this report have
been designed and implemented to help assess the usefulness of multiband
photography.

In each of the case studies, test results indicated that multiband
photography consistently yielded higher interpretation accuracies than any
type of single-band photography. In addition, black-and-white multiband
photos properly procured and displayed as false-color composite imagery in
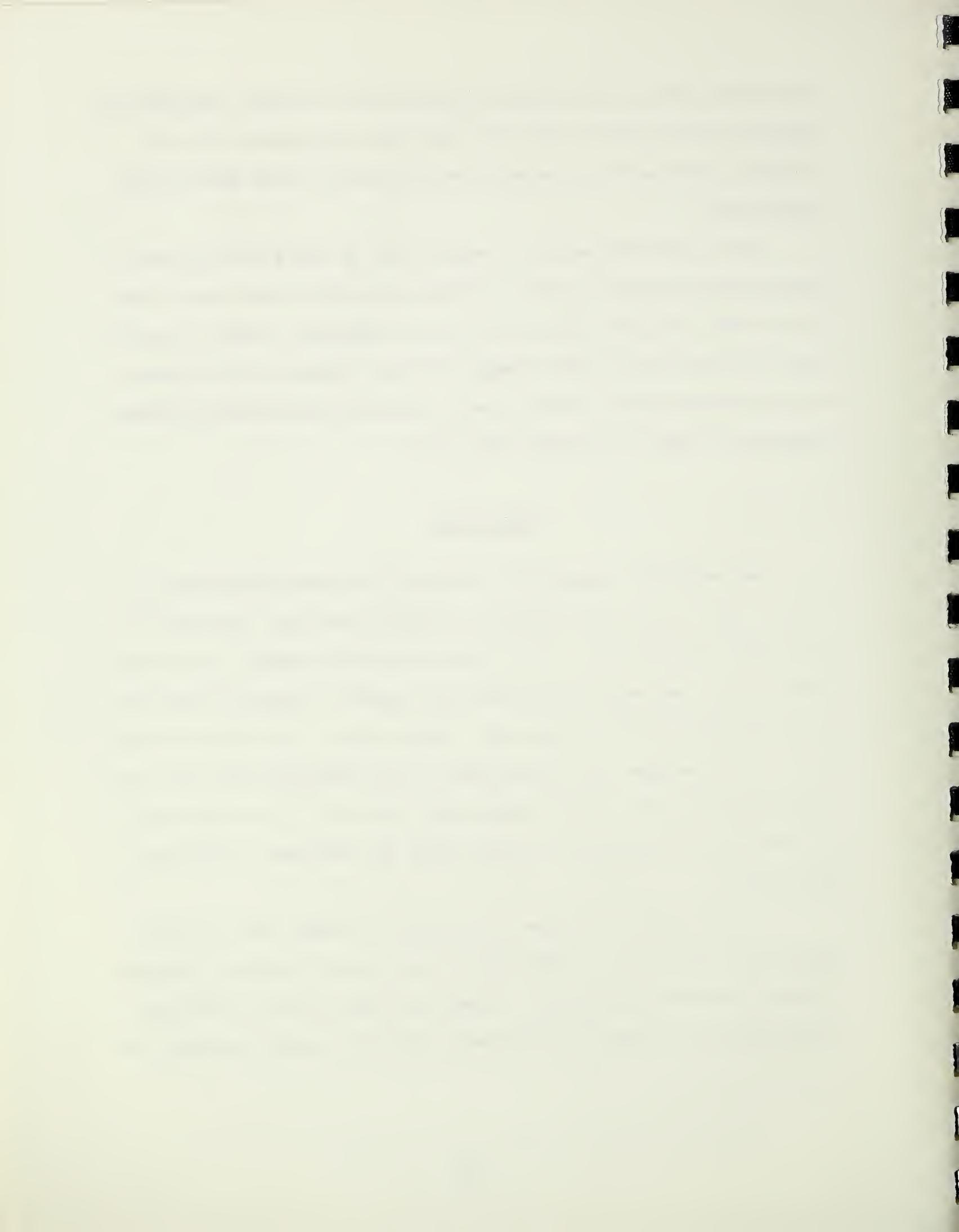
all cases rendered as much (or as little) information as conventional tri-emulsion layer color or false-color infrared films. Furthermore, by drawing on the flexibility afforded by multiband photography (i.e., optimum false-color enhancements of properly selected bandpasses), certain composite images were found to be superior to all other types of photography being tested--as was the case for the identification of coniferous trees at Yosemite Valley.

This does not mean that multiband photography in concert with additive color image enhancement is a panacea, especially when its usefulness is compared to other types of conventional photography. The merits of B/W multiband photography versus color and single-band, B/W photos have been the topic of numerous research studies. We feel that too often the assumed value of certain types of photography rests on the demonstrated superiority of one film type over another. Frequently overlooked is the assessment of flexibility of the photography's use, especially when two or more types of imagery may provide similar test results.

We do not advocate using multiband photography when conventional black-and-white or color will provide acceptable results. However, multiband photography does provide certain advantages and flexibility that color emulsions do not, including: (1) greater spatial resolution; (2) ability to compensate for poor exposure and extreme haze after photo acquisition; (3) the individual photographs can be used to reconstitute a color or false-color image; (4) the same photographs can be used to obtain additional false-color images currently unavailable with color emulsions; and (5) optimum spectral bands can be selected for the resource type of interest.
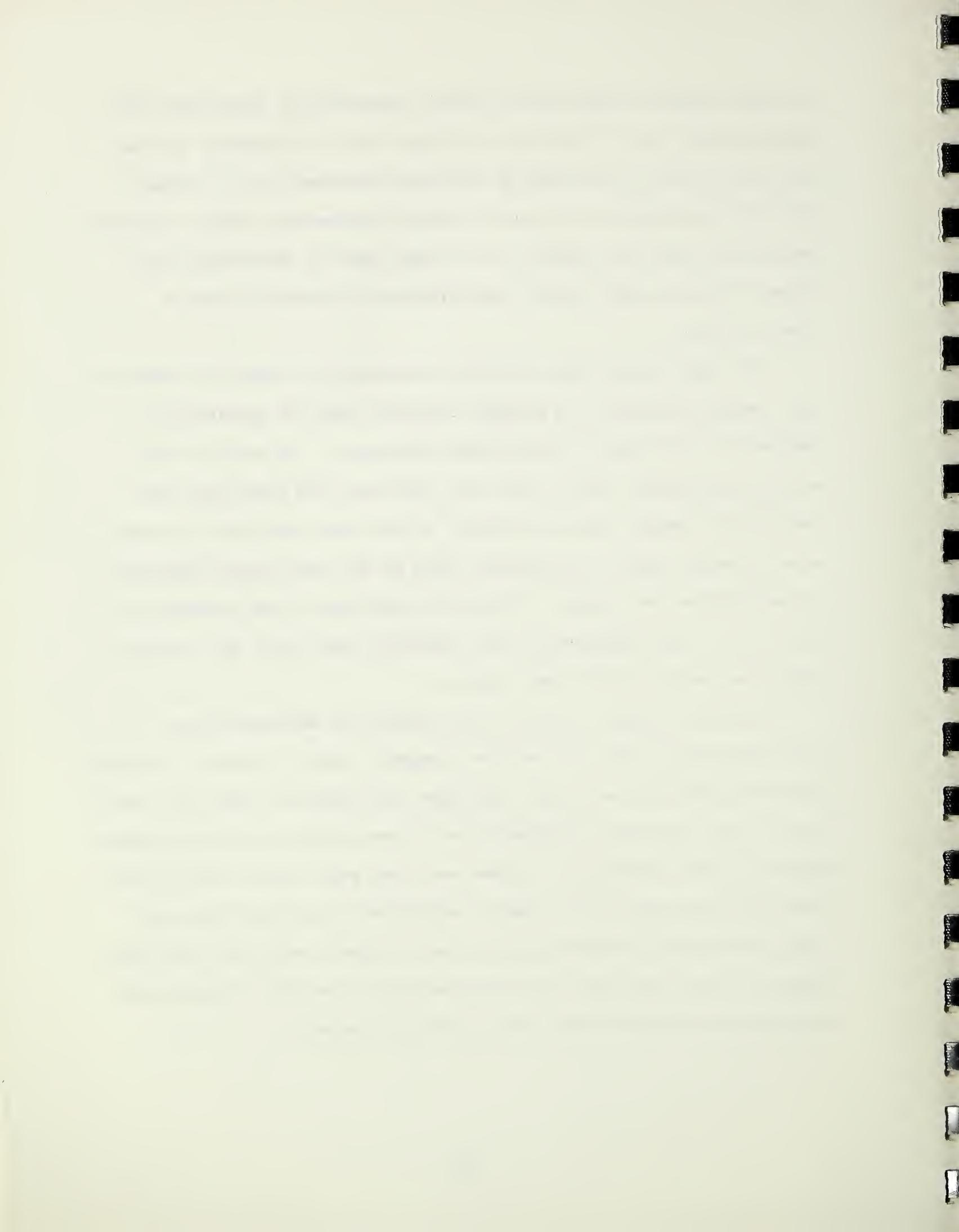
The case studies presented in this report seem to lend credence to the assumption that multiband techniques offer a flexibility in terms of image formation and interpretation that cannot easily be matched by any other conventional photographic technique. These facts, plus the imminent possibility of acquiring multiband imagery on a global basis from orbiting vehicles (e.g., Earth Resources Technology Satellites and Skylab), lead us to recommend that image analysts review the state-of-the-art techniques for acquiring and interpreting multiband imagery.

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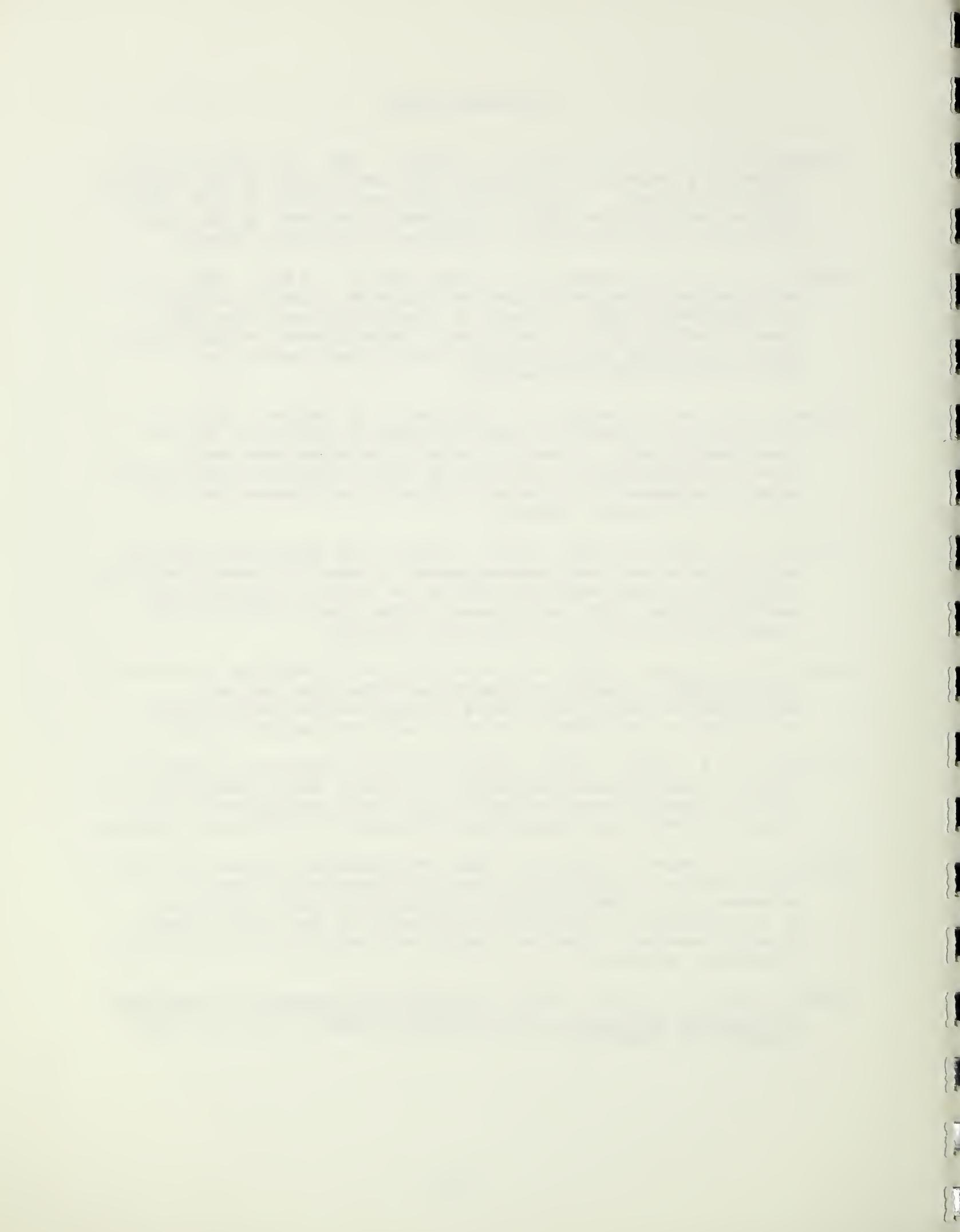
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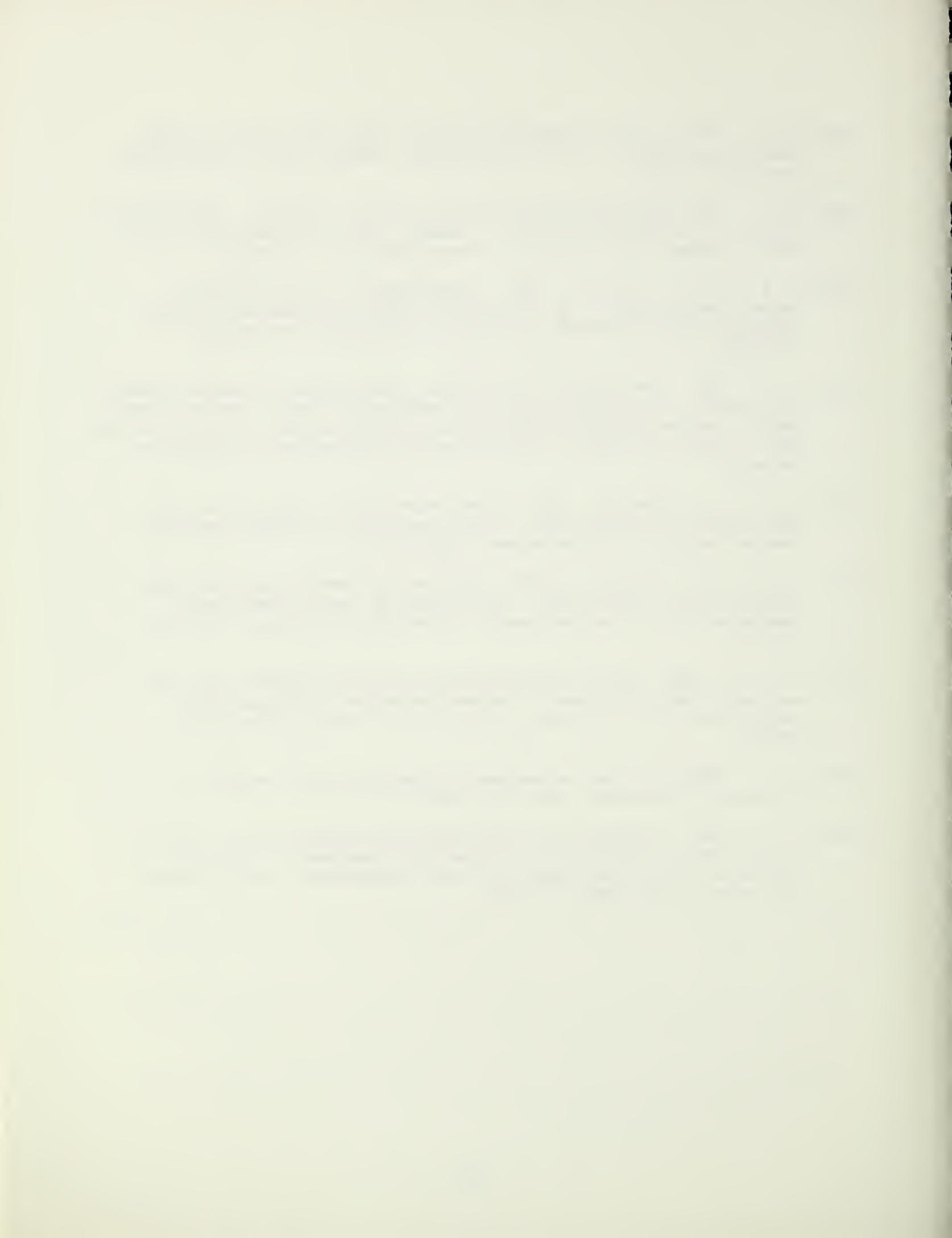
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